METAL PROGRESS

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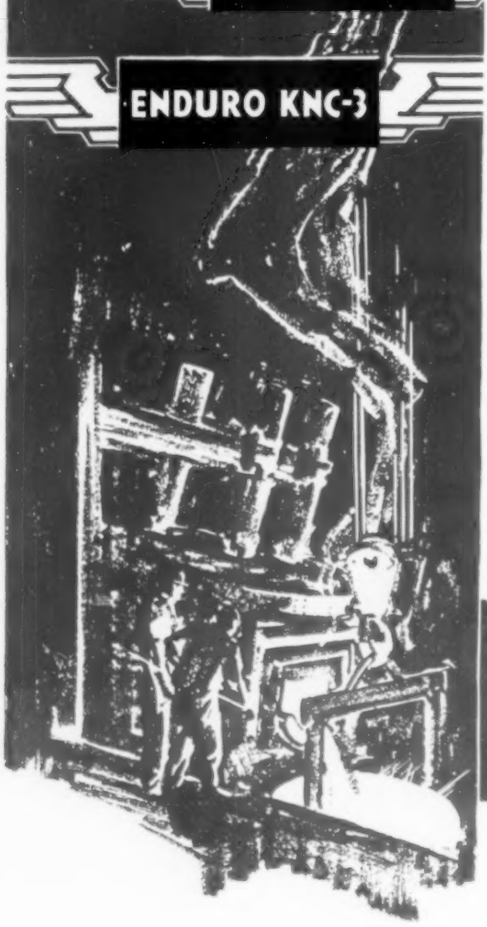

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Metal Progress

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Ernest E. Thum, Editor.

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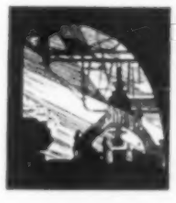

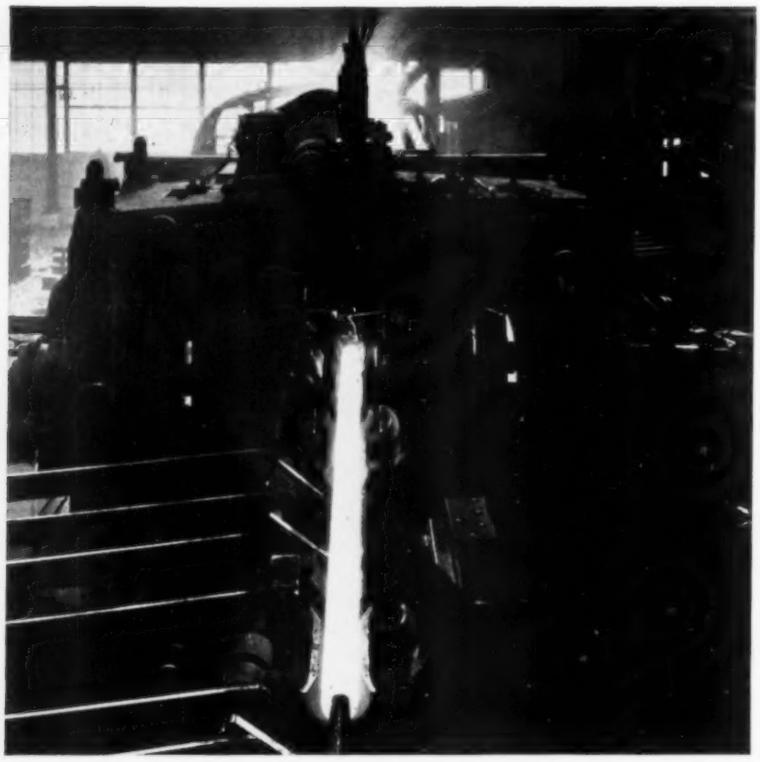

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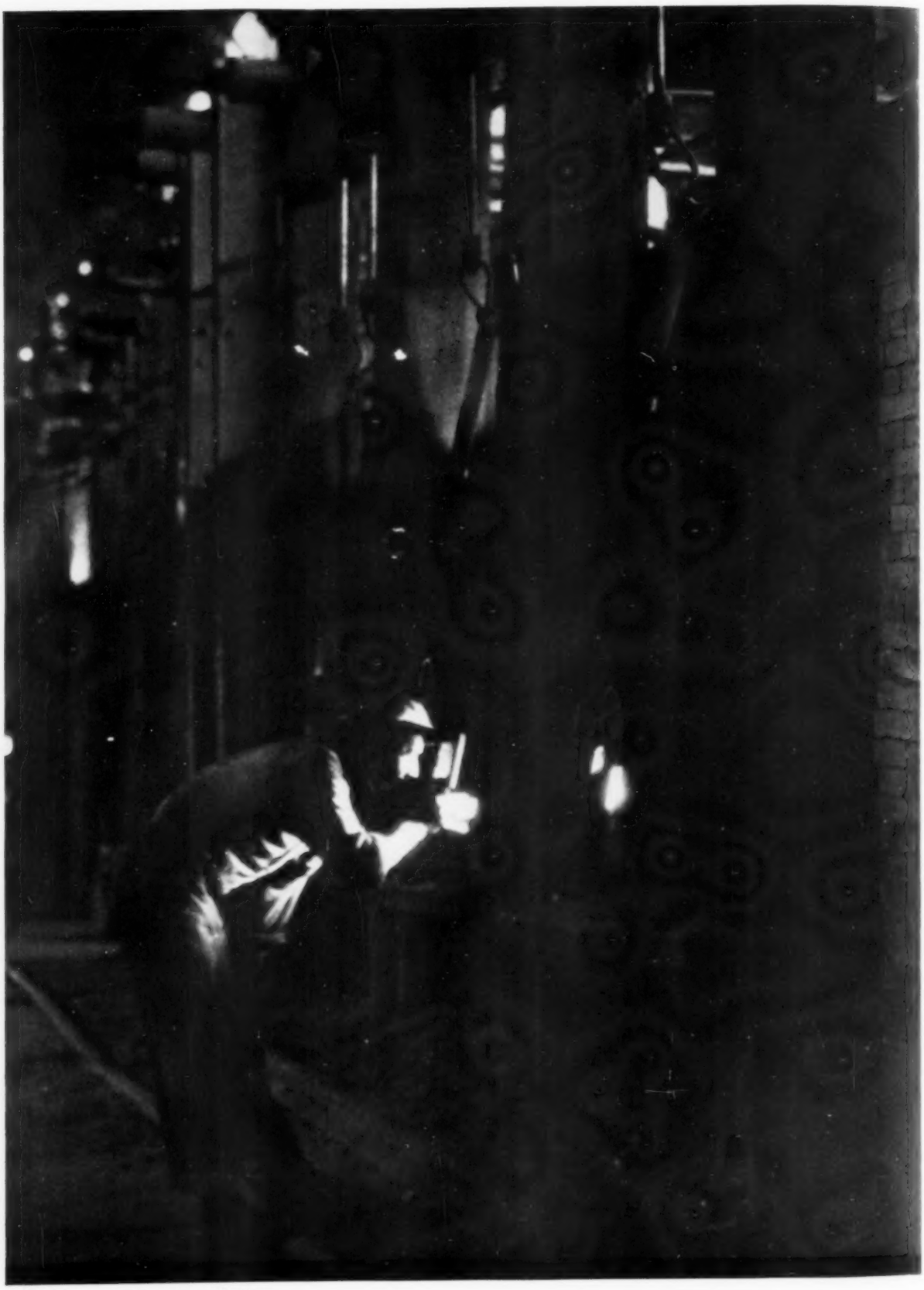


A Photograph by John P. Mudd
for The Midvale Company

VIGILANCE

By Dr. C. H. Herty, Jr.
Pittsburgh Experiment Station
U.S. Bureau of Mines

submicroscopic Inclusions in steel

Extracts from Sixth
Campbell Memorial Lecture
A.S.S.T. Convention, 1931

NON-METALLIC inclusions in steel were discussed broadly by Dr. Herty. He subdivided the subject into (*a*) inclusions visible at 250 diameters magnification, (*b*) particles invisible at that point, and (*c*) solid solution materials.

There is abundant evidence that particles invisible at 250 diameters exist in steel. As an example of this, ladle tests on an acid open-hearth heat in which the steel had been given a special deoxidizing treatment showed absolutely no inclusions, but the forged material contained silicate particles. An analysis of the two specimens by the electrolytic method showed that the ladle test contained 0.023% SiO_2 and that the section from the forging contained 0.621% SiO_2. Because silica is very slightly soluble in liquid steel, it was evident that the ladle metal contained silica so finely dispersed that it could not be seen at 250 diameters, and that this material had coalesced in the ingot mold.

There are three general methods of determining whether material is present in solid solution in steel: (*a*) By determining whether the material diffuses through solid steel, (*b*) by metallographic evidence (rather than proof) obtained at very high magnifications, in conjunction with chemical analyses of proved merit, and (*c*) by changes in physical properties of steel containing variable amounts of the constituent under consideration.

It is well known that oxygen as FeO is present as a solid solution in steel. The three methods of determining solid solubility all give a positive result, and, therefore, there must be no question of the fact. There is no direct evidence for solid solubility of MnO, but as this oxide is quite analogous to FeO, we should expect some solid solubility of this oxide.

Prof. Edward De Mille Campbell's pioneer researches at the turn of the century on the diffusion of sulphur through steel gave definite proof that sulphur has some solid solubility. Researches of other investigators have also indicated some solid solubility for FeS and less for MnS.

Rates of diffusion for various materials in solid steel have been determined by M. K. Ziegler as follows:

Material	Rate of Diffusion
MnS	0.0029 mm. per hr.
MnS + FeS	0.0720
FeS	0.1147
FeO	0.1434
Fe$_3$C	5.7300

There is no evidence of any appreciable solid solubility of SiO_2 or Al_2O_3 or of the silicates or aluminates high in these two constituents. SiO_2 must be slightly soluble in liquid steel, as evidenced by the silicon pickup in the acid open-hearth furnace. Its solubility in solid

steel is probably much too small to be measured by any direct method. On the other hand, the facts that particles high in silica or alumina are not attended by ferrite banding after rolling, and that MnO-FeO stringers or silicates high in FeO and MnO *do* show such banding, are certain indications that the oxides must be present in solution in the steel surrounding the inclusions.

As to alloy contamination, there is one set of variables not very often thought of, and that is the contamination of our plain carbon steels by residual alloys. In a survey carried on by the Bureau of Mines in cooperation with the Open-Hearth Committee of the American Institute of Mining and Metallurgical Engineers, it has been found that there is an average combined total of Cu, Cr, Ni, Sn, and Va in plain carbon steel amounting to 0.15%. Surely as large an amount of material as this must have its effect on some of the changes which take place in steel upon heat treatment or hot or cold working. This is particularly true of tin, which hardens steel tremendously during hot working.

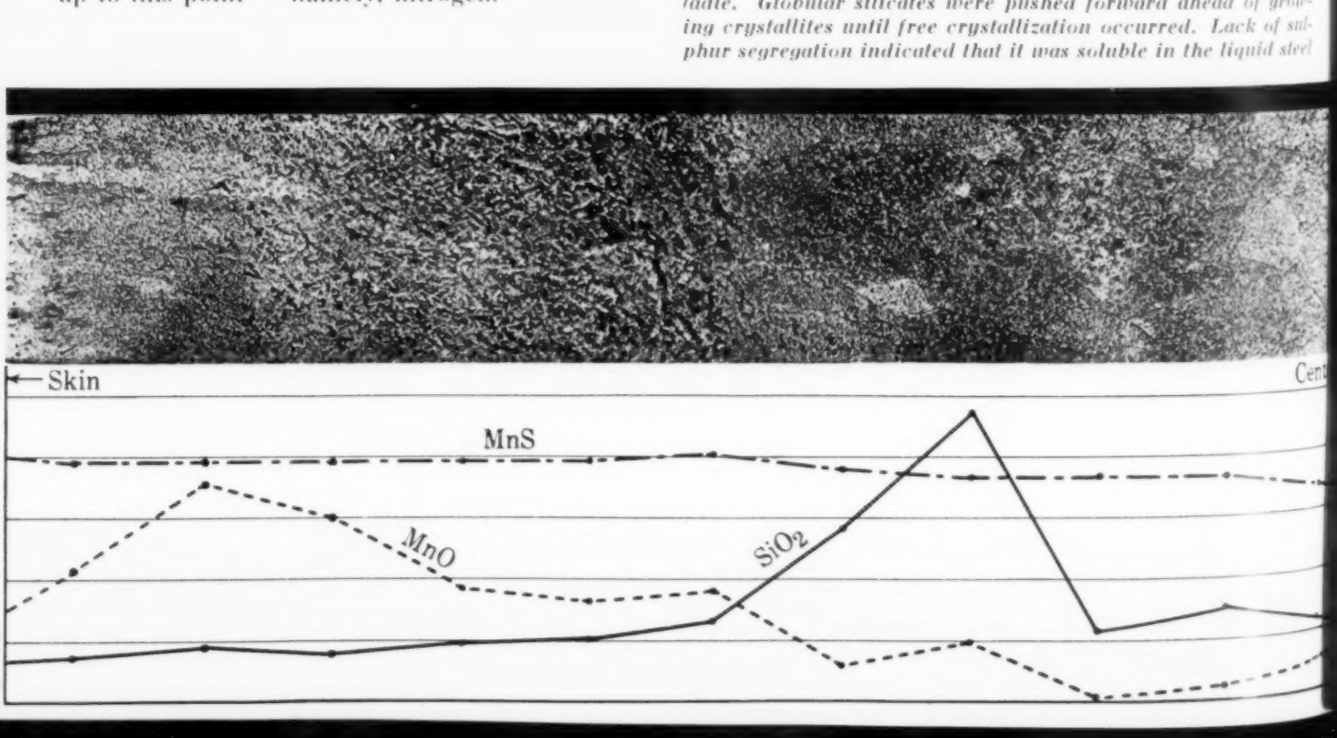
The source of inclusions in steel has been repeated so often that it will be unnecessary to go into detail here. They may be traced to one of three sources: (*a*) Contact with refractory material, (*b*) non-metallic matter brought in by the charge itself, and (*c*) the most prolific source is the deoxidation process. In respect to (*b*) above, there is some evidence that non-metallic matter tends to build up in a closed cycle in electric furnaces which use their own scrap. This has been thought to be particularly true of a non-metallic which has not been mentioned up to this point — namely, nitrogen.

Dr. Herty then devoted a section of his paper to the formation of inclusions during deoxidation, and showed how they are inseparable to the manufacture of steel and how they segregate in the ingot. Various types of killed and rimming steels are considered, and three of his electrolytically etched macrosections are shown on these pages and the next. He shows how a steel which is well deoxidized in the furnace will probably be much cleaner than one where too much dependence is placed on ladle additions, and also why it is more difficult to produce clean, low-carbon killed steel than clean, high-carbon killed steel. He continues:

It is my firm opinion that if the manganese specifications on most steels could be increased, the consumer would obtain a much cleaner product in a killed steel. The general manganese specification for low-carbon steels is so low that it is difficult to get enough manganese oxide into the metal to flux properly the oxides formed from the stronger deoxidizers. On account of the physical properties desired, in many grades of steel the manganese cannot be raised unless some other element is lowered, but wherever it is possible to raise the manganese specification it would seem advisable to do so.

Although the segregation of oxides and sulphides may be modified somewhat by the method of crystallization and the type of the ingot, there are only two possible ways to prevent such segregation: (*a*) To cast the steel into such small ingots that the entire mass solidifies

Section Taken From Skin to Center, Midway Between Middle and Top of 0.36% C Ingot. Killed steel deoxidized with silicospiegel and ferromanganese in furnace and ferrosilicon in ladle. Globular silicates were pushed forward ahead of growing crystallites until free crystallization occurred. Lack of sulphur segregation indicated that it was soluble in the liquid steel



almost instantaneously, and (*b*) to produce a steel essentially free from suspended non-metallic particles and extraordinarily low in sulphur.

A superficial survey of inclusions in steel generally ends in the conclusion that there is present in the steel a considerable number of particles which are of a different composition from the iron-carbon alloy itself and which must affect the physical properties in various degrees.

A difficulty which presents itself immediately in looking at the problem of the effect of inclusions in steel is that we have very little knowledge of the properties of the base metal. It is almost impossible to find any reliable data on pure alloys of iron, carbon, and manganese, for example. The data on commercial plain carbon steels are, of course, voluminous, but these data include many variables in addition to the predominant components iron, carbon, and manganese. Therefore, we have little indication as to the possibilities of varying the physical properties by purifying the metal on a commercial scale. Furthermore, there are few data on steels in which non-metallic inclusions are present in the maximum amounts possible.

Consequently, we have little knowledge as to the limits within which commercial steel is made and it would appear at the outset that one of the most important contributions which could be made to steel manufacture and consumption is to determine whether steels are capable of being improved considerably in physical properties or of simply being made more uniform.

In discussing the effect of inclusions visible at 250 diameters, Dr. Herty cites evidence to prove that failures of deep drawing material by ruptures parallel to the surface about 60% of the way to the center are due to non-metallics trapped among the secondary blowholes of the rimmed ingot.

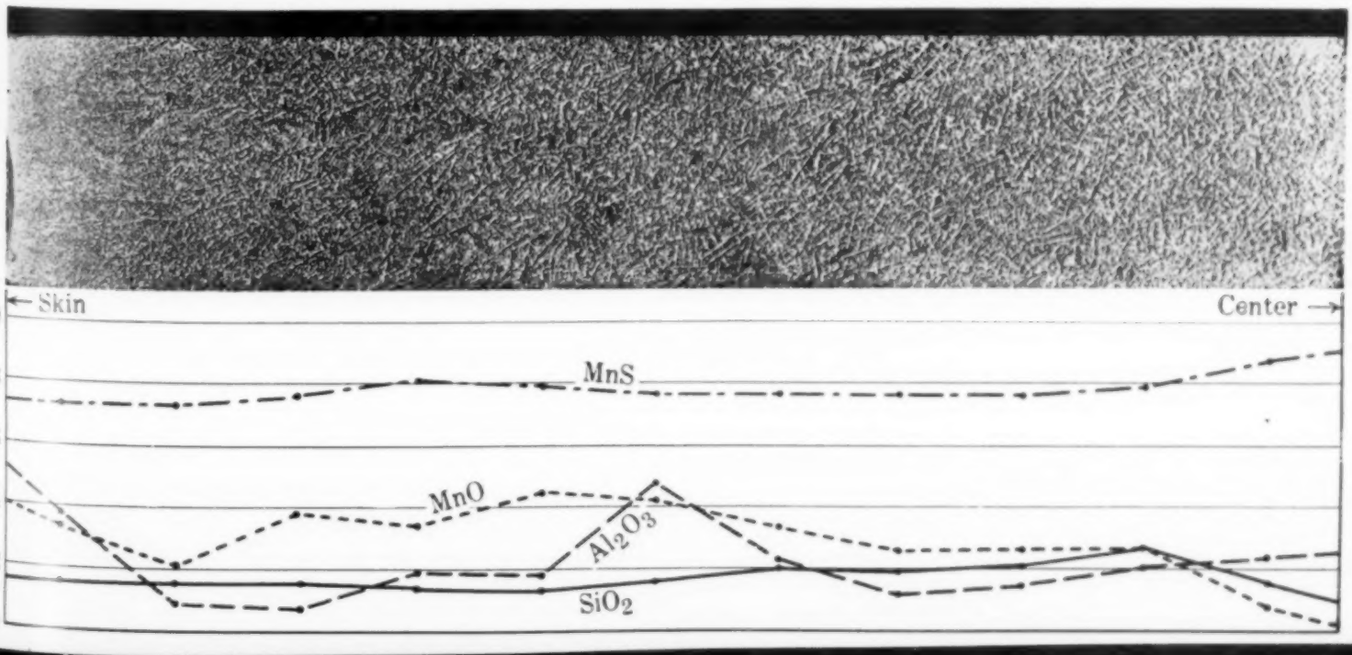
Another type of defect in deep drawing material is the apparent recrystallization of the metal on severe cold working. Such a defect is probably connected with the normal action of the iron-carbon-manganese alloy under these conditions. It is possible, however, that this condition of recrystallization might be accentuated by solid solution material.

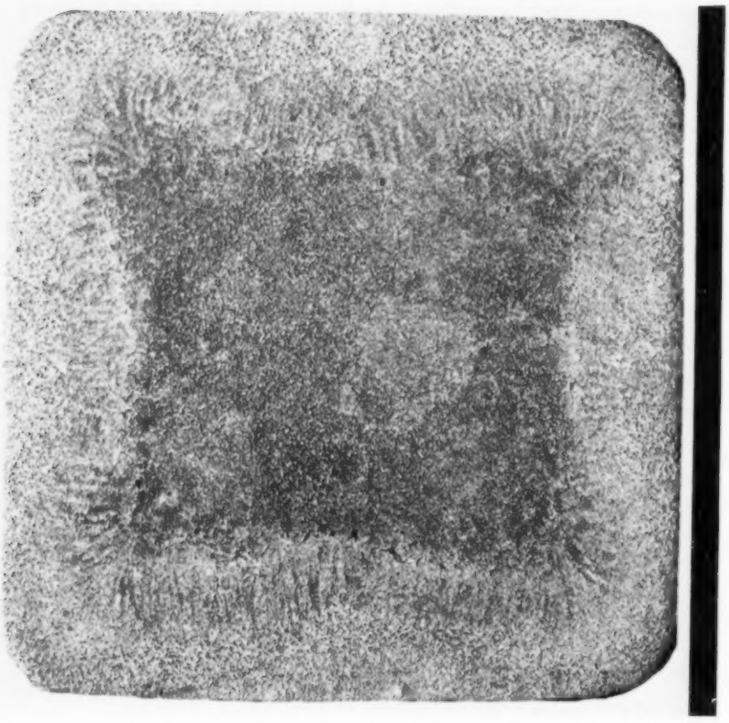
A great deal of stress has been placed on internal seams during the past few years due to the physical specifications set with respect to bend testing, upset testing, and the severe conditions imposed on bearing surfaces because of the increased speed of machinery. Here, again, there is unquestionably a point at which size of seam is critical, but this critical seam size has never been defined by published experimental investigations.

Internal seams are of two types — sulphide seams and oxide seams. Sulphide seams are usually associated with ghost lines, but oxide seams may be present in steels entirely free from this latter defect.

Internal seams are due solely to the method of steel making, as shown in the figure on page 42. This represents three practices of making steel, each rectangle representing the area of the step-down test, some 100 sq.in. of steel.

Dendritic Structure From Corresponding Portion of Ingot of 0.38% C Steel. Carbon was held by small addition of spiegel, and steel deoxidized in ladle with ferromanganese, ferrosilicon, and alsifer. Alumina segregation shows region where free crystallization of steel commenced





Cross-Section of Billet of Rimmed Steel After Electrolytic Etching. Zone of blow-holes, associated with increased metalloids, and sometimes with an excessive amount of non-metallics, occurs where free crystallization takes place in viscous metal

The top represents heats made by deoxidizing with 2,500 to 3,000 lb. of silico-spiegel, followed by a furnace addition of ferromanganese and an addition of ferrosilicon in the ladle. The middle diagram represents the same grade of steel, the amount of silico-spiegel being increased to 3,500 lb. The lowest represents the step-down test from heats in which a smaller amount of ferrosilicon was added in the ladle than the first-mentioned heats. On these last heats ghost lines were plainly visible, and the number of seams reported increased tremendously, due not only to silicates but also to sulphides, which segregated to a much greater extent in this steel.

An electrolytic etch is also shown on page 11 of a section of a 0.40% C shaft which contained numerous ghost lines and seams. In many of the ghost lines there were no signs of seams. A few seams occurred exactly in the center of the ghost line, but most of them were where there were no ghost lines. In this type of steel the silicates tend to segregate with the sulphur to some extent. In a more fully killed steel the sulphur and silicate segregation does not occur at the same point.

Dr. Herty believes that the physical properties of normally dirty steels do not vary to any marked degree with the total amount of inclusions present. The size of the inclusion appears to be of much more importance than the total amount of inclusions.

An important exception should be noted at this point. In an investigation in progress on an acid open-hearth alloy steel, a decided rise in tensile and impact strength was noted when the open-hearth practice was changed and a marked increase in cleanliness of the steel accompanied this change. A comparison of the physical properties and cleanliness of these steels is given below.

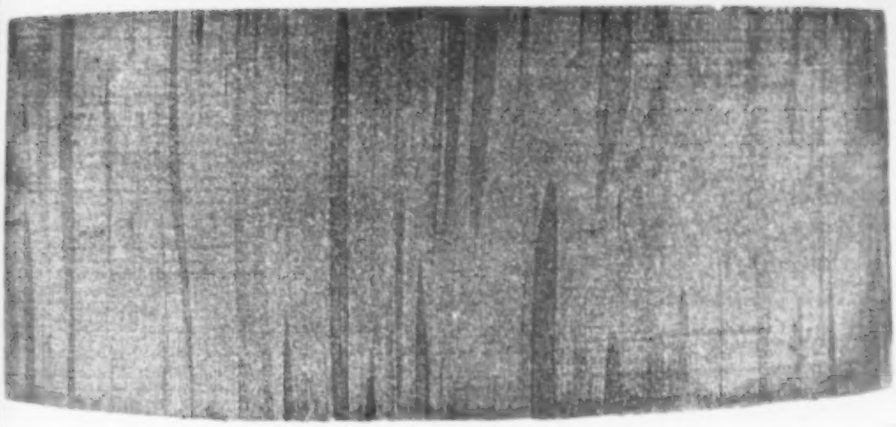
	Practice A	Practice B
Ultimate strength	121,500	127,000
Elastic limit	110,900	114,500
Elongation in 2 in.	14.4%	16.3%
Reduction of area	24.1%	30.9%
Izod impact value	18.0	28.0
SiO_2 in steel	0.026%	0.019%

These results, with those given for dirtier steels, would indicate that up to a certain point in cleanliness inclusion size is important, whereas beyond that point the total amount of inclusions becomes a factor.

It has been the general impression of investigators in this field that inclusions do not necessarily lower the fatigue limit of a given steel, but that a dirty steel will give variable results and a clean steel uniform results on fatigue testing.

The effect of material present in solid solution appears to be most pronounced in the structures obtained in iron alloys after various heat treatments, and probably involves not only a change in the iron-carbon diagram but also a change in the rate at which transformations occur and in the diffusion of carbon through the metal. The immense amount of experimental work on abnormal steel has focused attention on this phase of the inclusion problem during the past few years.

M. A. Grossmann, whose Campbell lecture of a year ago will be long remembered and much discussed, brought out clearly the effect of dissolved oxygen on carburized structures, attributing abnormality or normality to a tremendous change in the diffusion rate of carbon through steel below the critical point. This change in diffusion was thought to be due to the presence of dissolved oxygen. The presence



Ghost Lines in a Shaft Sometimes Have a Seam in the Very Center, But Most of the Seams Occur Elsewhere. Electrolytic etch, full size

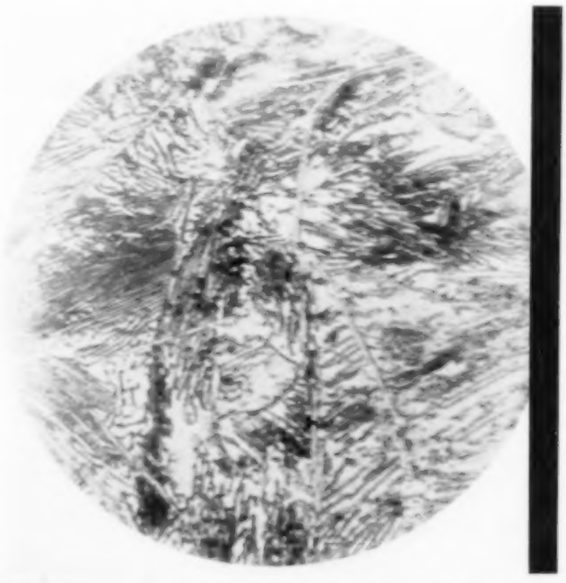
ed manganese in amounts above 0.30% apparently prevented the absorption of oxygen during carburizing and thus slowed down the rate of carbon diffusion, a normal structure resulting.

A point of interest here is the carburized structure of a vacuum-melted and vacuum-distilled iron, shown in the micrograph below. This structure is quite different from either a typical normal or abnormal steel. The oxygen content of this steel was 0.006%, determination by hydrogen reduction. Vacuum-melted iron-manganese alloys showed a gradual change from this type of structure to a normal structure, the most pronounced change being at about 0.20% manganese. Iron saturated with iron oxide in the liquid steel showed a completely abnormal structure after carburization.

Why did the vacuum-distilled iron not show a pronounced abnormal structure? It appears that Grossmann's explanation does not cover this type of metal or that there are variations in diffusion rates and crystallization characteristics not yet determined.

The appearance of ghost lines in steel has been attributed by numerous writers primarily to the crystallization of the ingot. It is unquestionably true that in large ingots "corner ghosts" are very difficult to eliminate. Ghost lines due to segregation of metalloids may be eliminated only by extremes in deoxidation and methods of casting ingots as yet impractical to the steel manufacturer. Ghost lines due to the segregation of non-metallic matter are, as shown in an earlier section, due to the segregation of sulphides and not silicates. It is impossible to prevent micro-segregation of sulphides, although it is possible to prevent macro-segregation.

Carburized Structure of Electrolytic Iron, Vacuum Melted and Vacuum Distilled. Oxygen content: 0.006%. Magnification 500 diameters



To demonstrate that deoxidation has a pronounced effect on ghost lines, I will refer to a series of heats under investigation at the present time where various amounts of deoxidizer were added, both in the furnace and in the ladle. When 0.07% silicon, in the form of silico-spiegel, was added to the furnace, it was necessary to add sufficient ferrosilicon to have the steel finish at least 0.15% silicon to prevent the formation of ghost lines. When the amount of silicon as silico-spiegel was increased to 0.10% in the furnace, ghost lines did not appear until the silicon in the ladle was lowered enough to give 0.09% silicon in the finished product.

In both types of deoxidation no evidence of ghost lines and very little sulphur segregation were found if the final silicon was kept above the limits given. When the silicon content of the steel dropped to these limits, sulphide segregation increased and ghost lines appeared. The evidence points definitely toward the deoxidation's preventing segregation of sulphur. In any event, ghost line formation due to sulphide segregation may be overcome by proper methods of deoxidizing the steel. The extent of ghost lines due to sulphur segregation resulting from incomplete deoxidation is shown in the shaft illustrated above.

The same reasoning should apply to ghost lines which contain phosphorus concentrations.

There appear to be many conflicting data

on the effect of ghost lines on the physical properties of steels. With such contradictory evidence on hand, it is obvious that no general conclusions may be drawn.

There are practically no data available on the effect of submicroscopic or solid solution oxides on the physical properties of steel. The exceptions to this statement are the results of a considerable amount of work which has been done on the physical properties of iron saturated with FeO. The ductility, impact strength, and elastic limit decreased very sharply upon the addition of iron oxide to pure iron, but the ultimate strength was not changed. There are absolutely no data available on the effect of manganese oxide or silica in solid solution, and from general experience there is only one property which very fine alumina particles appear to affect — that is, the ductility of cast steel.

It would appear from the preceding remarks that oxygen present in solid solution is of considerable importance in determining certain physical properties of steel; that finely divided inclusions have, with one exception, practically no effect; and, finally, that we know very little about this subject.

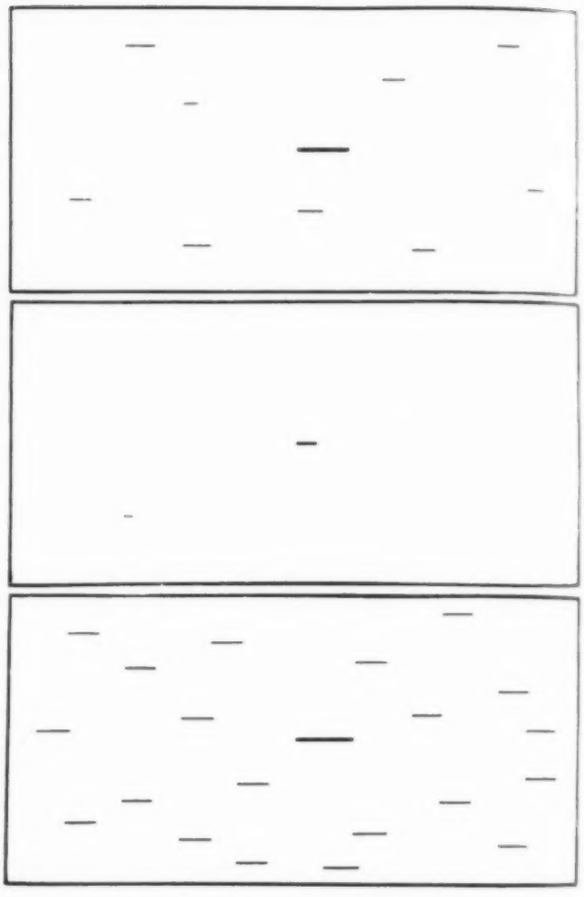
Four general conclusions may be drawn with regard to the present status and ultimate solution of the inclusion problem.

1. Before the inclusion problem can be properly evaluated it is necessary that a series of alloys, free from sulphur and oxygen, be prepared, and that the physical properties of these alloys be accurately determined. This would serve as a base line for comparison of commercial steels and steel-making methods.

2. From available data on various physical properties, it appears that large inclusions are much more harmful than small ones. Most metallurgical departments properly inspect steel for dirt and cleanliness at 100 diameters magnification.

3. Oxides and sulphides in solid solution are important when certain metallographic structures are to be avoided, or in some instances obtained. The difficulty of determining the amount of such solid solution material present in a steel has been, and will continue to be, an obstacle to the progress of this phase of steel treating and steel making.

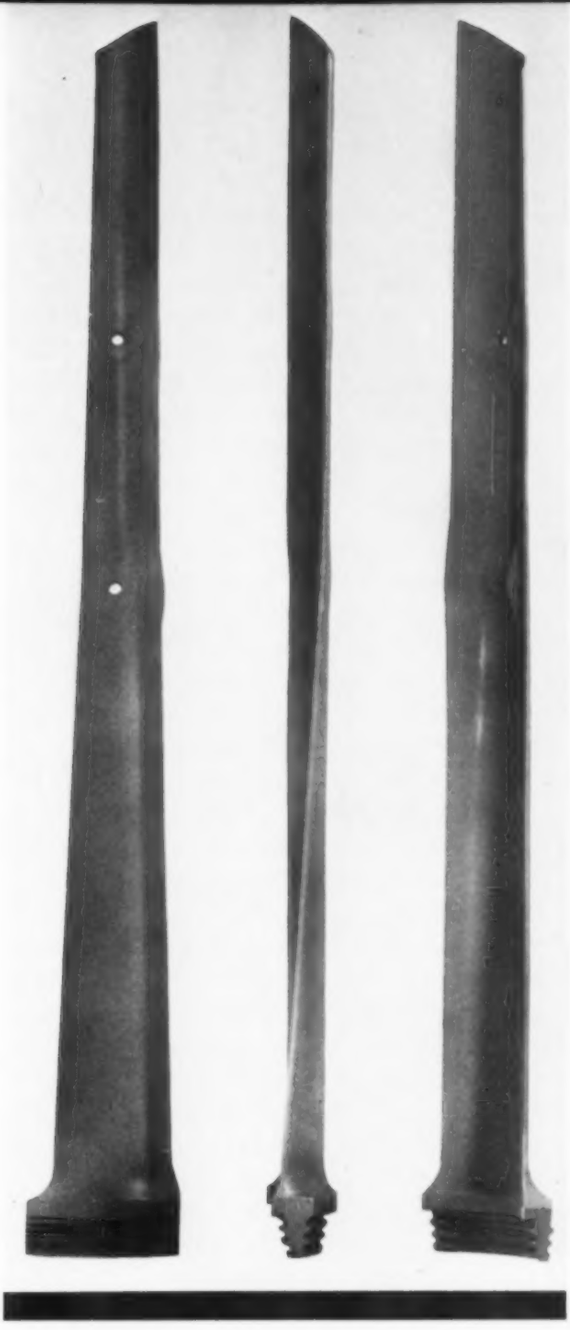
4. The steel maker supplies the consumer with steel to a given chemical analysis, combined, in many instances, with a physical grain size, or cleanliness specification. Oftentimes the filling of one specification will make it very difficult to meet another, and it is on this point that the consumer should most certainly put considerable thought. A higher manganese specification will promote greater cleanliness and a higher silicon specification will give freedom from at least one type of ghost line. The consumer is often entirely to blame for the kind of steel he gets because his specifications do not allow the steel maker to use available materials to the best advantage, and in some instances force him to use these materials to his own and the consumer's disadvantage. At some not too distant day the art of steel making will be superseded by the science of steel making, but the consumer must play his proper role in this change.



Relation of Internal Seams to Method of Deoxidation. Lines in each rectangle represent actual number and length of average number of seams in all step-down tests from heats made according to practices noted in text. The heavy line in center of each rectangle is average of longest seam in each step-down test

18-8

new facts and new uses



Turbine Blades, About 3 Ft. Long, Drop Forged of Chromium-Iron Alloy by Westinghouse Electric & Mfg. Co.

CONTINUING interest is being displayed in the corrosion-resistant steels, especially those containing 18% chromium and 8% nickel, as is proven by the fact that no less than six contributions to the recent A.S.S.T. Convention considered these alloys. Much of the discussion concerned the cause of the intergranular deterioration sometimes encountered in refinery equipment. However, new applications and data indicated a wider potentiality of usefulness for the high chromium steels and others of unconventional analyses.

A considerable quantity of 18-8 is being drawn into wire, and is being put to work where a high degree of corrosion resistance is needed. It therefore is competitive with plated carbon steel wire (which never has been highly regarded) and monel metal or bronze wire. It is perhaps the only alloy steel that has brought to the industry any property not reproducible in high grade carbon steel wire, patented and cold drawn. This property is corrosion resistance, rather than high strength or toughness.

W. H. Wills and J. K. Findley of Ludlum

Steel Co., Dunkirk, N. Y., while discussing "Manufacture, Properties and Uses of 18-8 Chromium-Nickel Steel Wire" point out that carbon must be held below 0.07%. Rods in 50-lb. coils are heated at 1,725° F. in hydrogen, quenched in water, pickled 60 min. in 10% H_2SO_4, washed, limed, and baked. After three roughing draws, each of about 30% reduction, another anneal is necessary. Drawing then continues in approximately 35% reductions, two draws being all that the material will stand, whereupon annealing, pickling, liming, and baking are necessary. Very fine wires (0.018 to 0.004 in.) may be finished in as many as 12 diamond dies in a continuous bench. Fine wires are pickled in strong HCl at 170° F.; in this condition the product has a "bright pickled finish." "Soft bright wire" is annealed by drawing through a tube of hydrogen at 2,025° F.

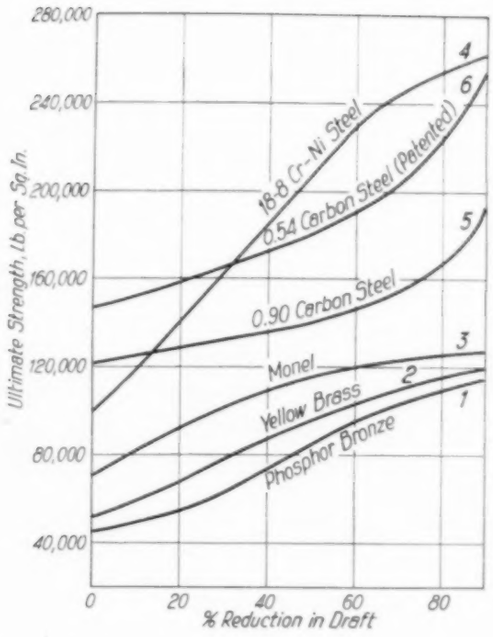
Cold work of wire drawing induces some of the austenite in the quenched rod to transform into ferrite and precipitate some carbide, thus increasing the electrical resistance, magnetism, and corrosion in strong mineral acids and alkalis. Wire still resists salt water, fruit juices, bleaching solutions, alum, and dilute nitric acid, and makes an excellent raw material for screens, wire cloth, screws and nails for filter presses, and other equipment in the chemical and paper industry. Steel cable for marine work is also in successful service; a stainless wire rope costs about five times as much as the best plow steel rope of equal strength. About half of the wire is drawn to relatively large diameter for welding rod. Spokes for steel automobile wheels consume a small amount.

The diagram on page 45 shows how the tensile strength of 18-8 compares with other common wires. Starting point was fully annealed 0.020-in. wire in all instances except curve 6 where the diameter at start was 0.192 in. Approximately 75% is the practical limit of draw for 18-8; beyond that the material is erratic in test behavior. Torsional strength of 18-8 is about 75% of its ultimate tensile strength. Its characteristic of rapid work-hardening limits its use in many upsetting or cold heading operations.

BELIEF held by power engineers that high chromium-iron alloys are superior materials for turbine blades was further reinforced by T. S. Fuller's studies on "Endurance Properties of Some Well-Known Steels in Steam." This paper has already been printed in abstract in METAL PROGRESS in July (page 79) and the principal conclusions were summarized in a data sheet in the same issue. When a 12½% Cr, 0.10% C alloy is heat treated to 100,000 lb. per sq.in. ultimate strength, its endurance limit is 61,000 lb. per sq.in. In dry steam up to 700° F. this is affected but little, but wet steam is very damaging, inducing corrosion fatigue at anything greater than 34,000 lb. per sq.in.

18-8 alloys have also been suggested for turbine blades. An extensive series of tests in dry steam at 300° F. (a common operating condition) showed an endurance of approximately 50,000 lb. per sq.in. in the hot rolled condition. Tempering at 1,200° F. for 6 hr. reduced this figure about 10%, but heating at 1,950° F. or higher for as little as 1 hr. cuts the endurance limit in half, and the damage cannot be corrected by extended heat treatments.

SINCE the stainless alloys are being introduced into machinery and other parts which are liable to receive severe shocks at extremes of atmospheric temperatures, their impact strengths at temperatures down as low as — 100° F. are important. Such data were reported among others by Robert Sergeson, Republic Steel Corp., Canton, Ohio, in his paper on the "Behavior of Some Irons and Steels Un-



Strength of Various Common Metals in Wire Form, as it Varies With Amount of Drawing Since Last Anneal

der Impact at Low Temperatures." The results for the high-chromium alloys are summarized in the graph at the bottom this page, where 1 represents Enduro KA-2 (17.5% Cr, 9.2% Ni, 0.08% C) water quenched from 1,950° F. to Brinell 143, 3 represents Enduro AA (18% Cr, 0.08% C) air cooled from 1,500° F. to Brinell 149, and 5 represents Enduro S (13.3% Cr, 0.10% C) furnace cooled from 1,500° F. and air cooled from 1,200°. Curves 2, 4 and 6 represent the respective materials in $1\frac{1}{16}$-in. bars after being cold drawn one draft to 1-in. round.

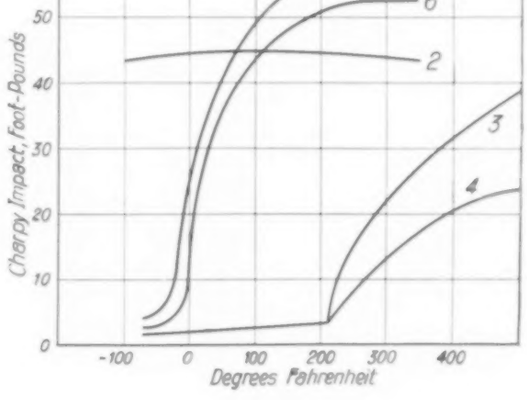
Since the 18% Cr steel exhibits crystalline fractures and brittleness until a temperature of 350° is reached, it should be gently warmed before flanging and also used at moderate temperatures if it is to resist shock. Mr. Sergeson notes some satisfactory trials of this material in locomotive firebox side sheets. The 13% Cr alloy is intermediate and is especially good at atmospheric temperatures.

OIL REFINERY equipment operates upon such a variety of materials, and uses such a variety of processes (temperatures and pressures) that its construction involves some intricate problems in the selection of metal. R. L. Duff, chief metallurgical engineer of Standard Oil Development Co., in a paper on "Corrosion Resistant Steels" emphasized that it was sometimes economical to build of ordinary steel and iron and endure replacement. When a process had been stabilized (so the equipment would probably wear out before becoming obsolete) and required the handling of corrosive products or high-sulphur crudes at high temperature or pressure, then the designer should balance high first cost and good operating efficiency secured by special alloys against freedom from frequent replacement, high insurance and inspection costs, which must be endured if conventional materials were selected. It is common to find that carbon steel tubes in cracking stills must be replaced after 2,000 hr.; 18-8 tubes might last over 10,000 hr.

Most refinery engineers would welcome a low-alloy steel, intermediate in cost, yet worth the extra. Mr. Duff noted that a $3\frac{1}{2}$% nickel steel prolonged the life of still bottoms one-third. Another promising corrosion-resisting alloy is a 4 to 6% chromium steel. In one Standard refinery it has given three times the life of carbon steel tubes, although it has no marked advantage over the carbon steel in creep strength at operating temperatures, toughness, or resistance to oxidation by flame.

On the other hand, even higher alloys have warranted their cost for certain extra-severe duties. One containing about 15% Cr and 35%

Impact Strength of Stainless Alloys in the Range — 100 to + 500° F.



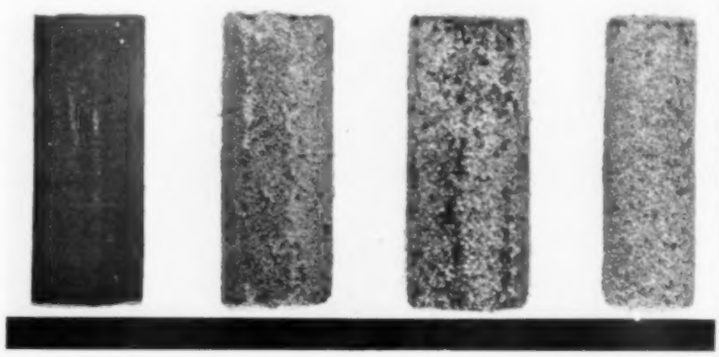
Ni has been found to be especially good to resist oxidation in fireboxes, but even this breaks down rapidly when high-sulphur fuel oils are burned. Equipment made of 20% Ni 8% Cr has also given a good account of itself when handling hot bottom products and sour distillates.

IN ELEVATED temperature service, especially in oil refining, an overheated 18-8 tube fails without a warning bulge or appreciable ductility. H. D. Newell, chief metallurgist, Babcock & Wilcox Tube Co., Beaver Falls, Pa., has therefore studied the ductility of this alloy in those temperature ranges where such failure is likely to occur. Some of the results were presented in a paper on "Influence of Grain Size on the Properties and Corrosion Resistance of the 18-8 Iron-Chromium-Nickel Alloy for Elevated Temperature Service."

His photomicrographs show that the fine grain of cold drawn alloy is progressively enlarged by both time and temperature at or above 1,850° F. Subsequent reheating for 150 hr. at 1,200° does not cause further grain growth. Mr. Newell's studies indicate that the increased corrosion after the latter treatment is due to the loss of grains from the surface, loosened at their edges by boundary attack. This is ascribed to the fact that precipitated carbides have gathered there (and these are photographed), and surrounding metal is depleted in chromium. Granulation at the surface in contact with the corroding medium is promoted by extra carbon in the alloy, by coarse grain size (a lesser amount of surface per unit volume), and by long heating at 1,000 to 1,450° F. Lower heating results in no damage because carbides cannot migrate; higher heating tends to repair the damage by permitting the corrosion-preventing chromium to diffuse from grain interiors to depleted grain shells. This effect was especially notable in metal containing 0.14% C and is shown in the accompanying view, actual size. All of these samples suffered attack after 3 hr. in boiling 10% H_2SO_4, even the hot rolled piece. Loss of fine grains from its surface gives a dull mossy appearance.

Rapid tensile tests at elevated temperatures indicate that 18-8 alloy containing 0.05% C holds nearly all its ductility up to 1,400° F. after 150 hr. at heat, as long as the previous quenching temperature is 1,900° F. or less, which results in but moderate grain growth. Creep strength, according to other investigators, is not harmed by a somewhat coarsened grain.

A combination of high creep strength and good ductility at elevated temperatures and high corrosion resistance is therefore to be secured by using a low-carbon alloy having relatively fine grain. The latter requirement means that high temperature treatments after mechanical work must be avoided.



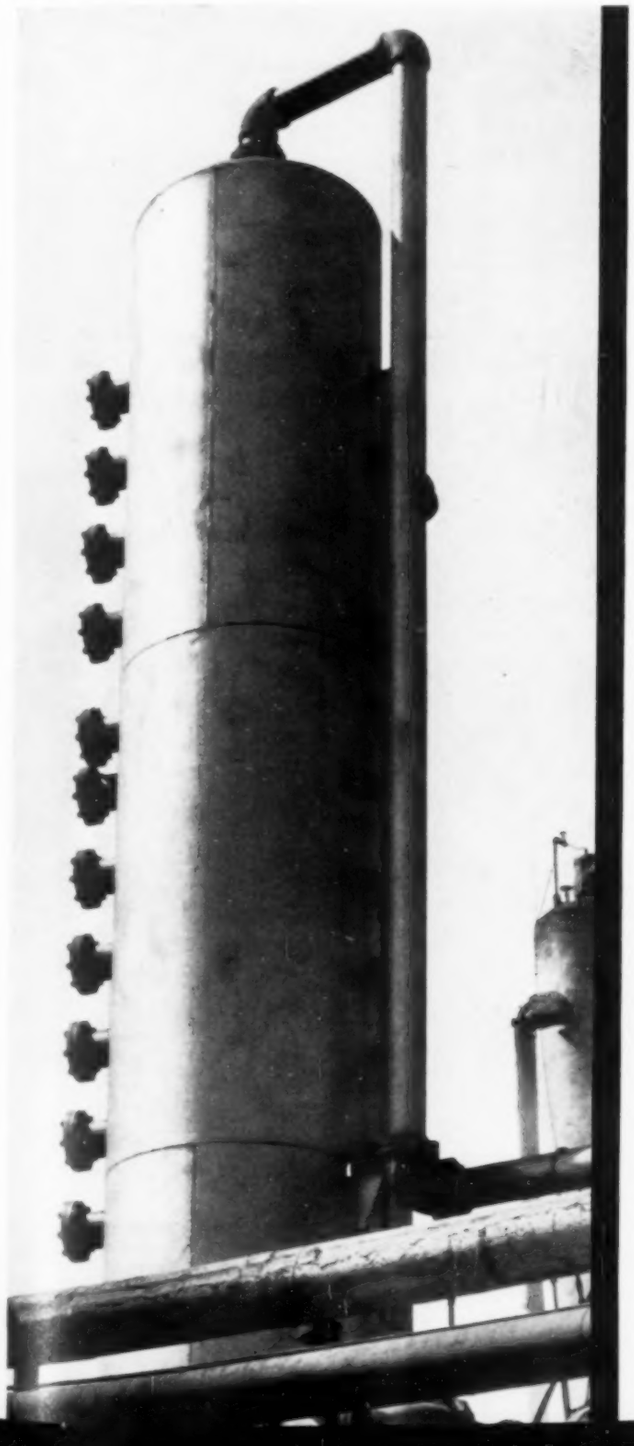
Corrosion Test on 18-8 Containing 0.14% Carbon. As rolled at left. Others were quenched from 1,900, 2,100 and 2,300° F. respectively and reheated 150 hr. at 1,200°

THIS INTRICATE PROBLEM of deterioration of 18-8 and related alloys has been studied intently by Dr. V. N. Krivobok of Carnegie Institute of Technology, Pittsburgh, and a number of graduate students in that institution's Bureau of Metallurgical Research. It is frequently supposed that if the alloy is magnetic it will also corrode. In a contribution to the A.S.S.T. convention entitled "Further Studies on Chromium-Nickel-Iron and Related Alloys" these workers described alloys containing 0.01 to 0.03% carbon which are not corroded by 100 hr. in boiling copper sulphate and sulphuric acid after any heat treatment, notwithstanding the fact that they may have magnetic susceptibilities as high as 200. Krivobok con-

cludes that long annealings at 1,200 to 1,400° F., which are most damaging to commercial alloys containing 0.06 to 0.22% carbon, cause a precipitation of carbide and its migration and accumulation at grain boundaries. Simultaneously chromium, nickel, and carbon are diffusing from solid solution toward regions impoverished by the carbide formation. The former action has most to do with intergranular corrosion; the latter has most to do with the magnetic properties.

Boiling copper sulphate and sulphuric acid is a very severe corroding medium, and its results are difficult to evaluate quantitatively. The authors have found that 10% HCl at room temperature gives uniform results which can be plotted as loss in milligrams per square centimeter against time, and the results hold a definite relationship to the magnetic susceptibility. Loss in weight in HCl also agrees with the result of extensive studies on the effect of corroding atmospheres at high temperature on 18-8 under stress. Consequently, the authors recommend that magnetic susceptibility be taken as an approximate measure of the liability of commerical alloys toward intergranular decomposition.

Courtesy Standard Oil Co. of Ohio



Granted that carbide precipitation is the cause of deterioration, the obvious remedy would be to keep the carbon within the solubility limits of iron-nickel-chromium solid solution. This is so low (approximately 0.03% C) that it cannot be done commercially. The next best thing is to keep the carbon as low as possible. Even though the alloy with 0.06% C is not immune, the range where decomposition occurs is narrowed and its upper limit reduced. For instance, such an alloy is safe for indefinite stays at 1,600° F., whereas a 0.11% C 18-8 will quickly deteriorate at that temperature.

Some uses require the maximum possible strength, and for these the carbon cannot be reduced indefinitely. The correct method of approach would then be to add elements which would increase the solubility of carbon at all temperatures or resist migration of carbides. Copper and molybdenum are elements with these properties. They also increase strength and creep values. Phase changes seem to be effectively suppressed in a 0.13% C 18-8 containing 1.5% Cu and 1.5% Mo; its magnetic susceptibility is 2 or less and it resists acid attack after long stays at 1,200 or 1,400° F. Lesser amounts of these two alloying metals appear to limit the dangerous temperature ranges in the same way as described above for low-carbon high-chromium alloys.

18-8 with added alloying elements have been studied, but the field is almost limitless. Additions of copper or molybdenum alone up to 3% do not seem to help avoid decomposition or prevent phase change. A combination of the two seems to be required, although the test results must be interpreted with care.

Twist Drills

proving their quality

MUCH has been written in the last 30 years about the improvement of tool steels, and very much indeed has been accomplished in that direction. A reader of the literature would assume that nearly all of the work has been done on lathe tools, since little has been said about the other varieties of cutting tools, such as drills, milling cutters, taps and reamers. As a matter of fact, these far more intricate and precise tools have had a development corresponding to that enjoyed by their more rough-and-ready relatives used in lathes and planers.

Nor are the leading manufacturers of these small tools convinced that their product has yet reached perfection. Extensive research programs are investigating many aspects of the product. As an instance, Morse Twist Drill & Machine Co. at New Bedford, Mass., enters its 67th year with enough developmental problems current to occupy the entire time of a staff of six engineers and researchers. Ample specialized equipment enables this organization to measure definitely the performance of any set of tools, and to appraise correctly the resultant of any variation in manufacture or design proposed as an improvement over the standard practice. This article will endeavor to indicate how these tests are performed on twist drills.

It may be noted that improvements in small tools come about by changes in materials, in outer form (design), or in inner structure. During years gone by, important changes have been made in the steels used, the fluting, and the heat treatment — items typifying each of these three main classifications. We may profitably consider them more in detail to indicate the directions in which present researches are progressing.

Prior to the advent of high speed steels small tools were ordinarily made of plain high

Series of Drills at Beginning of Test

carbon crucible steels (1.10 to 1.20% carbon). This type is still largely used; in recent years 0.40 to 0.60% chromium has been added to avoid black fractures (excess iron carbide breaking down into iron and free carbon) and to increase the depth of hardening. Vanadium (0.15 to 0.25%) is also added to toughen the tool. "Non-shrinking" steels are also used for taps and dies.

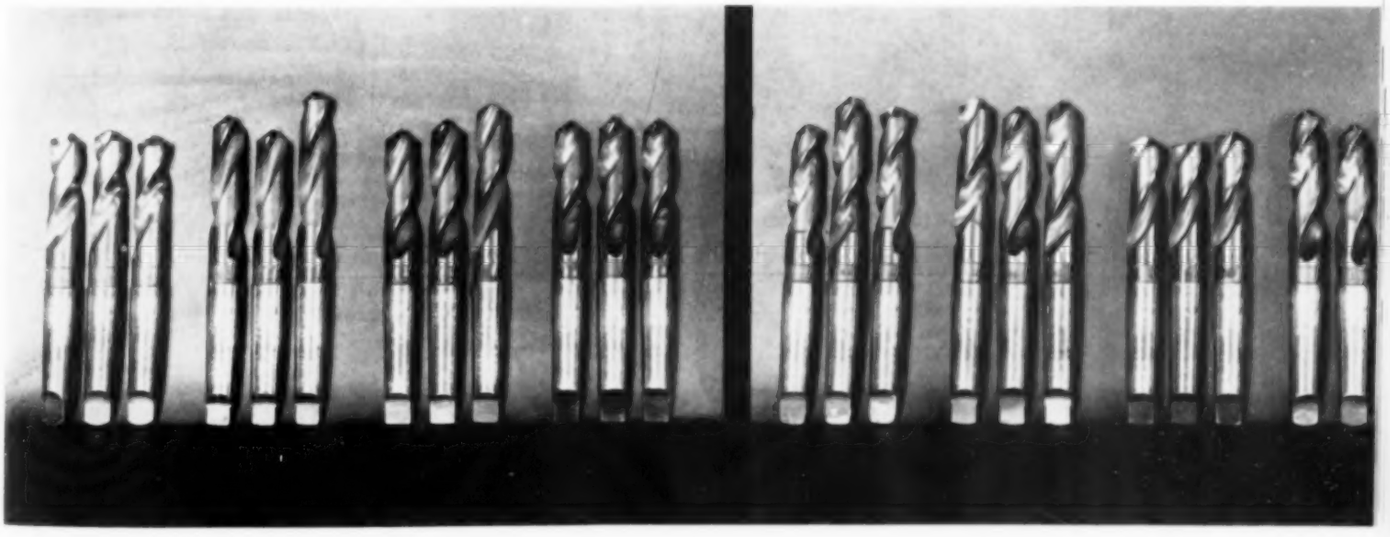
High speed steels found slow footing in the field of drills, reamers and the like, but in course of time the conservatism of the old machinists has been overcome. An evolution in the latter class is now under way in the cobalt-bearing high speeds; when the analysis contains as much as 8% the tools are hard and tough enough to negotiate Hadfield's manganese steel, and many other tough, abrasive alloys and non-metallics, and these steels are undoubtedly a great advance in metal suitable for forming into special duty tools.

Preliminary tests on each shipment of steel, before it is put into production at the Morse plant, consist of a complete chemical analysis, a deep acid etch, hardness before and after hardening, and size and distribution of carbides in the steel as received. Furthermore, a disc is hardened in the regular production, and the fracture examined. Drills smaller than $\frac{5}{16}$ in. are made of ground rod or wire, and each piece is inspected minutely for surface condition. The object of this work is, of course, to insure that the steel is as close as possible to the type regarded as ideal for the tools to be made — that is to say, "ideal" in the present state of knowledge.

Mechanical Improvements

As an illustration of the way drills are being improved by refinements and changes in design (the second category noted above) it may be mentioned that the drills, not so long ago, were made from flat stock and without spiral grooves. Now-a-days even the smallest

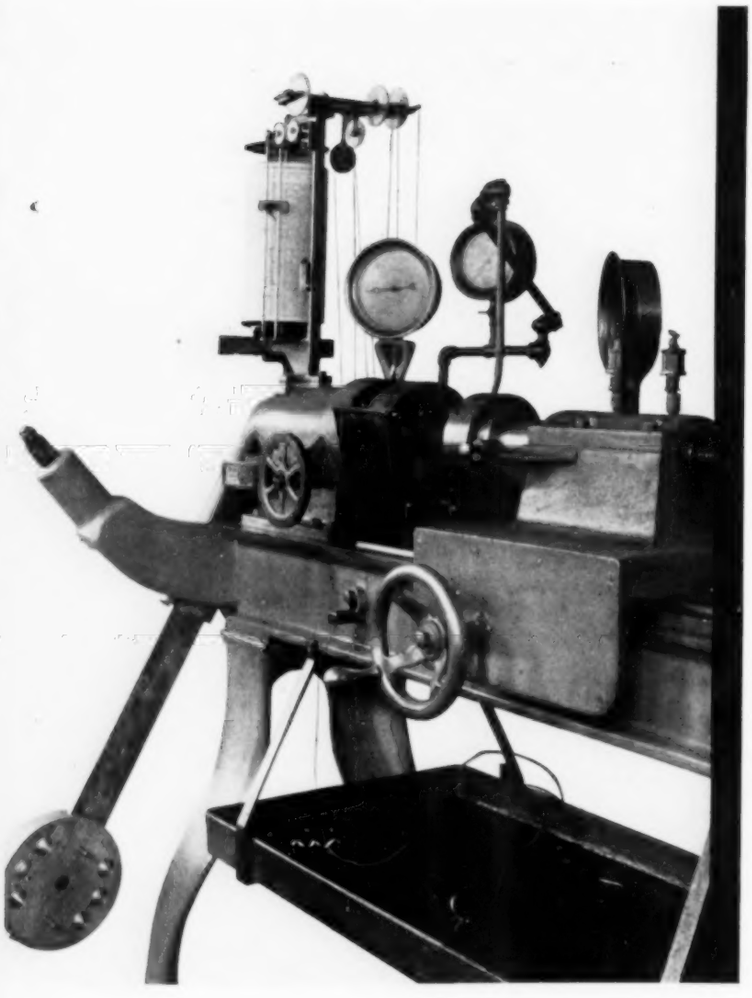
Drills as They Appeared After Testing



ones are studied to give them correct spiral angles, shape and area of groove, web thickness, clearances and surface finish.

Such matters as these (being non-metallurgical) need not be discussed at length in METAL PROGRESS. It is worthy of emphasis, however, that twist drills are being made with a continually increasing accuracy in dimension, and it is surprising to find some users (who are anxious to get the most out of each tool) permitting their mechanics to grind drills by hand on a loose wheel, instead of insisting on the use of fixtures which insure that the drill point is maintained in the exact center, where it must be for satisfactory performance. As a matter of fact, innumerable laboratory tests show that when a good tool is properly ground the penetration after, say, the sixth regrind is greater than on the first or second — provided only that the grinding is correctly and accurately carried out.

Precision Equipment for Drawing the Torque-Depth Curve on Drill During Test and for Measuring the Point Pressures



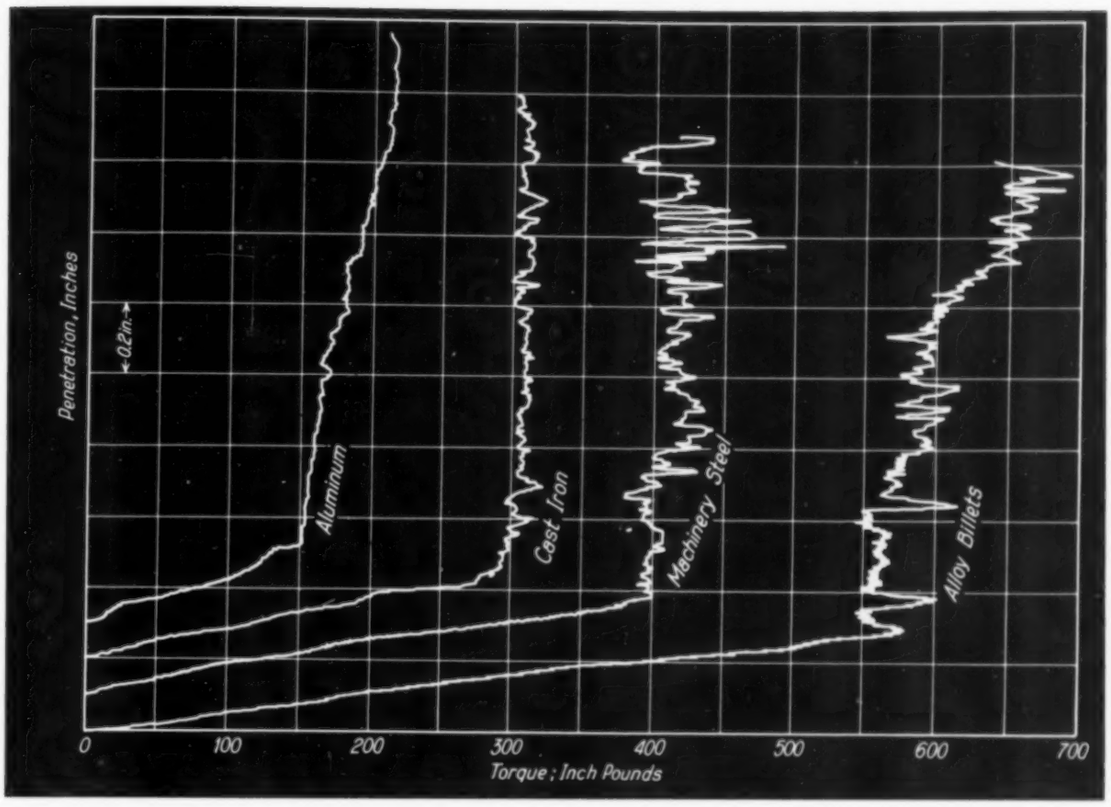
Improvements in heat treatment (the third possible approach to perfection in small tools) continue. The human eye pyrometer and coal-fired furnaces have long since been entirely superseded by automatic control, gas, oil or electric furnaces held to within 10° at the high heat. Atmospheric control (either by use of salt, lead or oil bath, or gas control in gas or electric furnaces) is common. Normalizing (to convert the spheroidized structure easiest to machine, and to readjust internal stresses) prior to cutting the thread on taps, and thus minimizing dimensional change in subsequent hardening, is now commonly practiced.

Only recently has it been discovered that the atmosphere in a high heat muffle has an influence on the toughness of a tool, as well as upon its surface condition — a matter which, of course, is under further investigation. Extensive studies at the Morse Twist Drill & Machine Co.'s plant are also under way on the influence of various factors in the drawing operation, such as temperature, time at temperature, and multiple or repeated draw.

While standardized treatments of standard analyses are ideal from a production standpoint, experience indicates that special purpose tools can be produced satisfactorily by variations in the tempering schedule; such special tools are generally indistinguishable by hardness or other quick inspection tests, but unquestionably have a superiority over stock tools when run in the specialized conditions for which they are adapted.

These preliminary remarks indicate the infinite number of variations which may be possible in adjusting a manufacturing program with the idea of producing an improved twist drill. The next question is, how can the effect of all these operations be integrated and evaluated in a figure which has some relation to performance in a customer's plant?

A general indication of the variation in working conditions is gained from a test in a special efficiency machine, shown on this page, manufactured by Tinius Olsen. It is adapted to draw automatically a curve giving the varia-



Torque-Depth Curves for 1-In. Drills Working Respectively in Aluminum, Cast Iron, Machine Steel, and Alloy Steel

tion in torque as the drill penetrates. Point pressure is shown on a dial gage, read from time to time by the attendant. Some representative curves are reproduced, showing the wide differences in operating conditions which must be met. Similar curves are drawn in all competitive tests.

Four curves are plotted on the same sheet, the origins being shifted slightly upward to avoid confusion. All drills were 1 in. diameter, and the feed was always constant, 0.010 in. per rotation.

High speed drills were used on both aluminum and toughened chromium-nickel steel. Point pressure when working in aluminum varied from 500 to 800 lb.; the speed was 440 r.p.m., the torque quickly rose to 150 in-lb. when the tool was properly bedded, and then increased gradually with deepening hole to a maximum of 215 in-lb. Rapid variations in torque, noticeable on other curves, are absent. When drilling the alloy steel billet the speed was reduced to 170 r.p.m., but the point pressure was much higher: 1,900 lb. Torque increased fairly steadily with deepening hole, reaching a maximum of 695 in-lb.

Intermediate between these extremes are curves showing the stresses in a 1-in. drill of carbon steel when drilling cast iron and machinery steel. Speed in cast iron was 100 r.p.m.; point pressure, 875 lb. Torque of 325 in-lb. was quite steady and increased not at all with deepening hole. A similar drill in machinery steel, at the same speed required point pressure of 1,050 lb. Torque showed a tendency to increase to a maximum of 490 in-lb; the most marked chacteristic, however, is the rapid fluctuation at the extreme depth of hole.

Final evaluation of a drill's excellence is made by actual drilling tests. Suppose a new heat treatment schedule for $\frac{1}{2}$-in. drill is to be investigated. A certain proportion, selected at random from a tote pan of appropriate tools coming from the last machining operation, is laid aside and given the desired processing. After heat treatment, cleaning and grinding, six

tools from the normal run and six tools from the special run would be selected by the head of the research department.

First, these tools would be carefully inspected, measured and tested for hardness, to assure that each tool conformed to the tolerances permitted by commercial considerations, or by the special conditions of the test. Then three of each set would be put to work, the other three reserved for reference.

Test drilling is done in one of a battery of special drill presses, rugged machines, capable of steady performance at great overloads. Each machine is driven by a direct connected motor, and an ammeter and voltmeter are mounted in the direct vision of the operator, so that variations in power input can be instantly noted.

Routine of Tests

A succession of holes are now drilled in 2-in. billets of S.A.E. 3240 steel. (Larger drills would work on 3-in. slabs of the same material; small drills on 1-in. plate.) This "armor plate," carefully heat treated to Brinell 241 to 271, is adopted because it is the toughest variety of steel readily procurable with the desired uniformity. While it is seldom if ever encountered in a production job, Morse engineers believe its use for test purposes is justifiable, because it shortens the time to breakdown to a reasonable degree. As it is, a comparative test is seldom completed within 10 days of continuous drilling.

Rotations per minute are figured on the basis of 50 ft. per min. peripheral speed. For a $\frac{13}{16}$-in. drill the test would be conducted at 200 r.p.m. and a feed of 0.0075 in. — very rapid work on such tough plate, the best tool requiring regrind after about 20 linear inches of hole. Soluble oil is used for lubricant.

Test routine would be to drill three holes with the first drill, remove it and drill the next three with No. 1 drill of the other set; then three with No. 2 of the standard set, three with No. 2 of the comparative set, and so on in continuous alteration and procession. In this way unavoidable variations in operating conditions are equally distributed among the tools under test. A principal variation would be a change in hardness of the test block, edge to center of the slab. The routine described insures that each tool would get its share of a tough edge or a soft center.

Drilling is continued in this manner until all the tools have dulled and require regrinding (notations being made of the total depth drilled by each tool). All tools are then sharpened on a Sellers drill grinder, and the whole performance repeated. In fact, the test is not considered complete, and totals added up, until the tool has been dulled for the sixth time. If one of the tools should break, or sliver back so the stub end can no longer be used, it is regarded as being still in the test, its performance being rated zero for all subsequent grinds. This is considered justifiable because the testing conditions, although severe, would not smash a first quality drill.

Evidence that a drill is dull is adequately gained from one or a combination of three observations. When the drill stops cutting and starts "wearing" out the bottom of the hole the ammeter needle immediately indicates a considerable jump in the power input. Again, a drill in good condition will throw out a long curly chip from each flute — any variation in amount or appearance of cuttings from the two sides indicates that the tool is coming to an end of its useful life. Furthermore, a dull tool, even in a rigid, strong drill press, is much too noisy, and emits unmistakable and heavy chattering sounds.

The table shows results of a recently completed test on four sets of $\frac{13}{16}$-in. drills.

Grind	Depth Drilled				Source of Billet	Average Hardness of Billets
	Set A	Set B	Set C	Set D		
1	54	42	38	21	X	269
2	65	60	36	36	X	269
3	74	43	37	45	X	262
4	39	35	25	23	Y	269
5	194	128	35	18	X	241
6	176	96	80	46	X	241
Total Depth Total Usage	602 5.0 in.	404 6.56 in.	251 7.62 in.	189 10.06 in.		

On first glance it might seem that the variations in the drilling after the individual grinds are so great that valid conclusions cannot be drawn. However, closer inspection reveals that A turned in the best performance in each test and had the highest total; B with the next highest total was second in each test except the

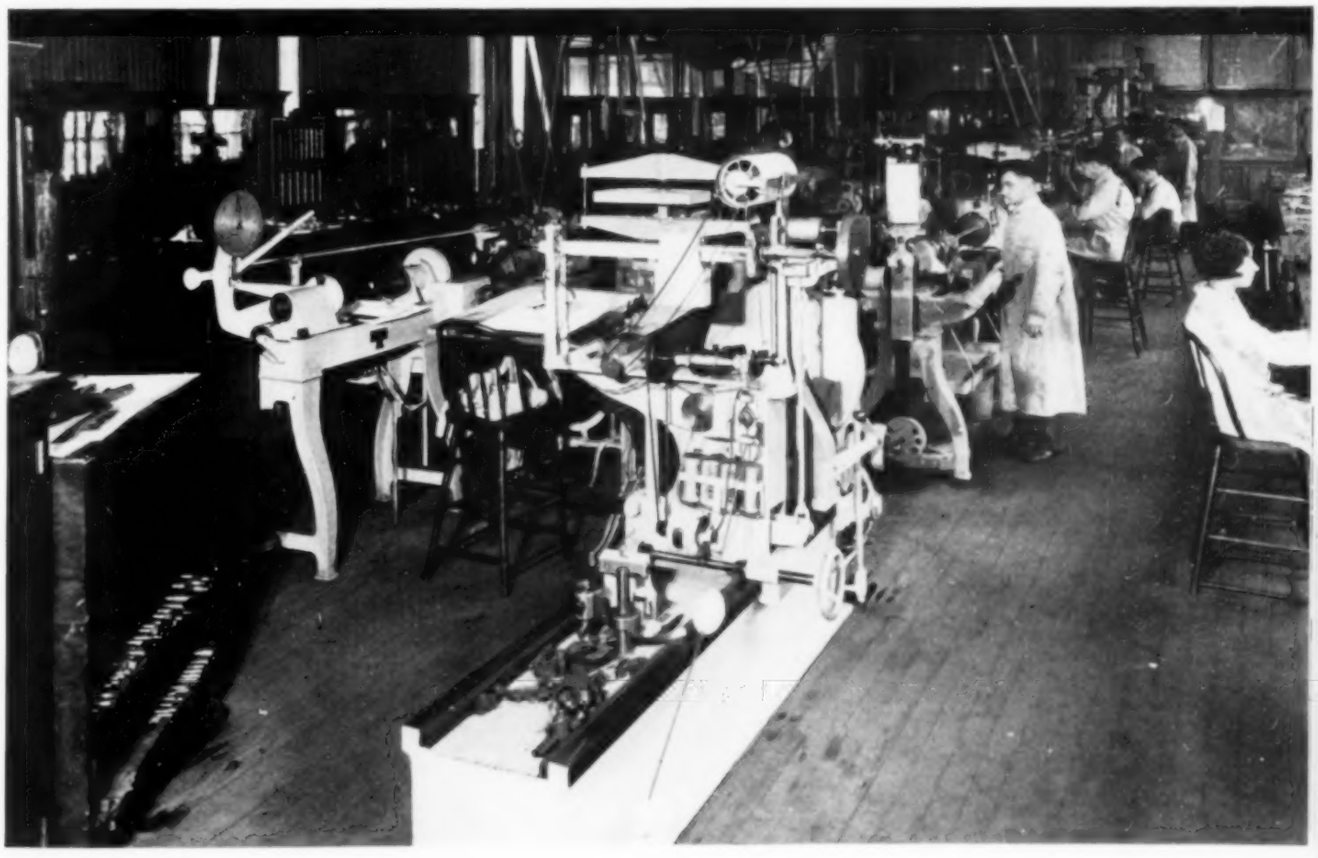
third; and C with the third highest was third when tested after four of the six grinds. This consistency is a pretty sure indication that the drills represented by Set A are not only better than the others, but are superior to Set C.

Set D is included because after the third grind one of the drills broke; and the subsequent figures give the actual performance of only two drills. Low results obtained for the first two grinds justify the conclusion that this fracture was not a piece of bad luck, but an indication of inferior quality.

Variation of work done with minor variations in the test block is also clearly indicated by the figure in the table. Toward the end of the third grind the supply of test billets was exhausted, and pending arrival of a new shipment, some steel which conformed to chemical and hardness specifications was secured from a second source. Despite its proper hardness, this steel was at least one-third harder to drill than the lot formerly used. The new supply from the old source, on the other hand, which Brinelled 241 instead of 269, is more than twice as easy to cut! Such variations in machinability, billet to billet, however, do not affect the final rating when the drills are properly used in rotation every three holes.

A scientist might object to the above described test because the results are relative and cannot be interpreted except in the light of figures secured for a set of standard tools inserted in each test. Continued testing of standardized tools seems to be a wasteful repetition of work. The pragmatist rejoins that by means of such tests, continued over a period of years, the Morse organization has not only been able to perfect its own manufacturing technique, but has built up a body of experience which enables it to develop promptly special tools for special duties as need for them arises in the customers' plants from time to time.

The Testing Department in the Plant of the Morse Twist Drill & Machine Co., New Bedford, Mass., Is Devoted to the Investigation of the Cutting Efficiency of Tools



By Thomas Dockray
Metallurgist
Eastern Rolling Mill Co.
Baltimore, Md.

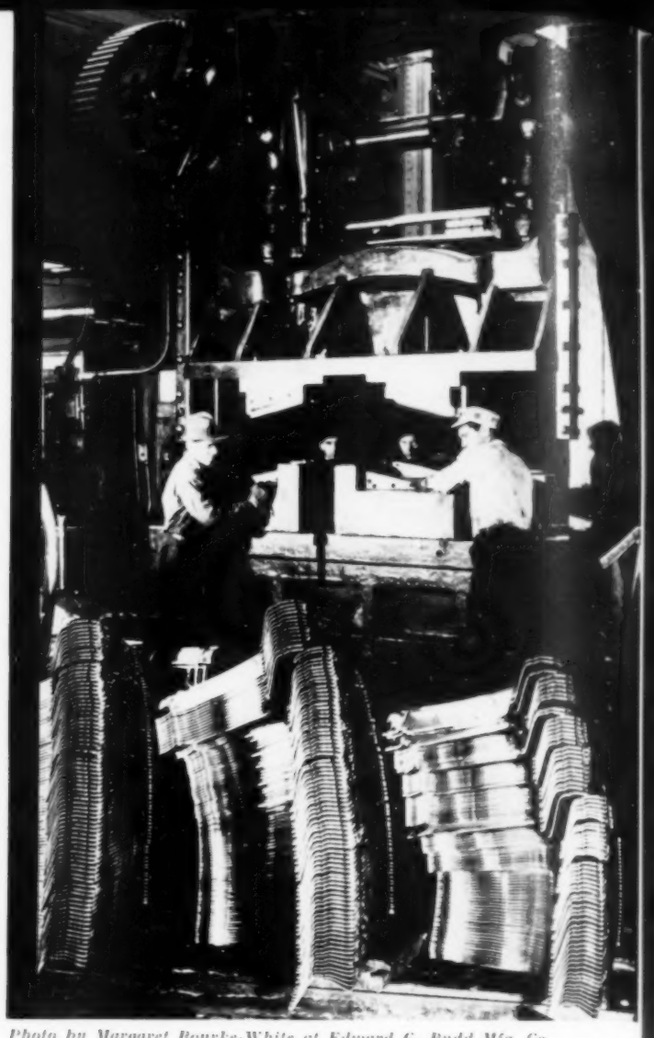


Photo by Margaret Bourke-White at Edward G. Budd Mfg. Co.

Sheet Steel

its drawing quality

A paper read at
A.S.S.T. Convention
Boston, Sept. 1931

DURING the last few years much progress has been made in the fabrication of extra deep drawing automobile sheets as well as in the art of stamping intricate shapes from this material. But the art of testing it has made no progress. Attempts are made by some consumers to evaluate the quality by certain tests which have proved to be fairly responsive, but the fact remains that very often, notwithstanding an excellent test or run of samples, the steel in question would give an unexpectedly high breakage.

Different consumers use the Rockwell hardness test, either alone or in combination with cupping tests. Elongation of a tensile specimen is also thought to indicate quality.

Let us first consider, from a mill metallurgist's point of view, the problem of meeting certain requirements for extra deep drawing stock, stated by the above tests. The principal operations affecting the physical properties of sheets are *(a)* hot rolling, *(b)* normalizing, *(c)* box annealing, *(d)* cold rolling, *(e)* the steel itself, and *(f)* its age.

A commercial sheet for extra deep drawing would aim for a certain ladle analysis, but, in my opinion, non-homogeneity of the steel ingot, going clear through to the individual sheet and consecutive sheets, is the biggest factor in creating non-homogeneous lifts of sheets.

Representative conditions caused by segregation would show carbon 0.10% at top of ingot, 0.05% at bottom; manganese 0.38% top and 0.35% bottom; phosphorus 0.018% and 0.008%

respectively; and sulphur 0.045% and 0.020%. There is a further variation due to whether the ingot was the first or the last to be poured, the latter ingots having the carbon around 0.12% at the top and the other elements correspondingly increased. To the steel maker meeting a carbon bracket of 5 points, this range would represent an excellent heat. But consider the effect of this variation of carbon upon the physical properties.

Upon normalizing, this typical ingot would give a range of probably 12 points of Rockwell hardness, the bracket going up or down depending on the normalizing practice, and the width of the bracket depending purely upon the carbon spread. Annealing accentuates the effect, softening the lowest carbon sheet more than the highest, thus enlarging the bracket of hardness value noted on annealed sheets. Hence, in this typical ingot would be found sheets varying from, say B46 to B58, or from B35 to B50, or from B26 to B45, according to the normalizing and annealing conditions.

This definite unchangeable range of hardness in any lift of sheets cannot be changed if every sheet is given the same processing.

Any sheet steel manufacturer who is given a certain hardness specification to meet questions whether the customer is aware of the minimum and maximum values in a lift of sheets which he has found to give satisfactory results in the press. Probably he has tested the hardness of two or three sheets in that lift, and if these and other tests on other lifts were about the same he might assume that the whole lift was of the same hardness. This is fallacious. It is very probable that in such a lift there would be 5 to 10% with a hardness of B55 where B40 to B50 was specified and where the test showed a value of B46.

It is practically impossible to obtain consistently ingots of steel where the carbon would be in the range, say 0.05 to 0.10%, but even if the carbon range were to remain consistently either higher or lower, a hardness range of B40 to B50 could be obtained by suitable normalizing practice alone. The question arises whether this type of sheet would be always suitable for very difficult stampings. The author's experience is that it would not.

In the most intricate stamping the softest and most ductile sheet would respond the most freely to the dies. A sheet that is normalized only is not the softest, for any system of cooling with the present type of normalizing furnace cannot duplicate the softening effect of the box annealing furnace. As pointed out, box annealing softens, but also widens the hardness bracket, and it can be seen that a range of 10 points of Rockwell, if specified, draws a very strict line which it is impossible to meet consistently.

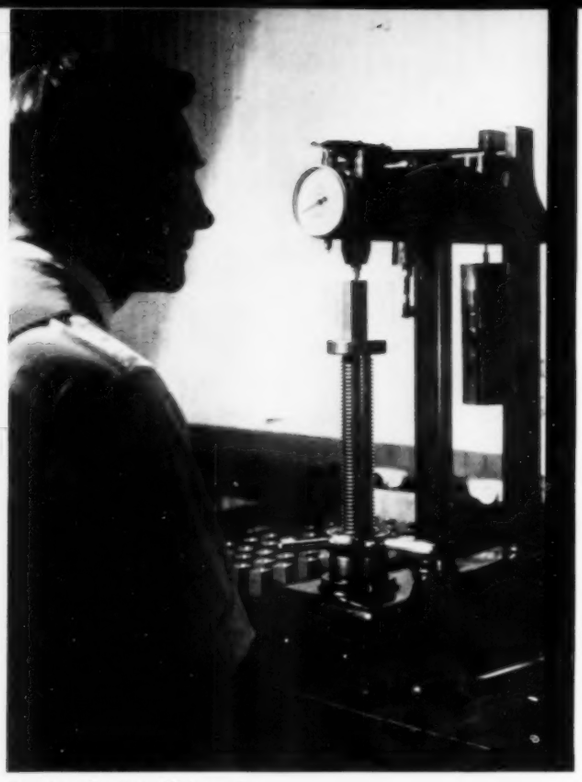
In the cupping test there is again a difference due to chemical composition, but the percentage variation is not so great.

Taking the typical ingot previously mentioned, the high and low readings for a normalized 20-gage sheet would be about 10.00 mm. to 10.60 mm. After annealing this spread is increased, and the cups would be greater, say 10.60 to 11.10 mm. for sheets from top and bottom of ingot, respectively.

As to the tensile test: It is the author's experience that the softest sheet will *probably* give the highest elongation. The word "softest" is used advisedly, for excellent elongation might depend more upon the orientation of the grains after annealing than upon other factors. Taking concrete figures: 30% elongation in 8 in. for a 2¾-in. wide specimen can be attained without any annealing from the bottom of the typical ingot, but not so easily from the top. With fair annealing, a figure of 35% could be obtained with a low-carbon sheet; good annealing would give this figure with the high-carbon sheet.

A very good idea of the quality of annealing can be obtained by watching the flow which takes place in the specimen under a tensile stress. This was explained at length by Messrs. Winlock and Lavergne in METAL PROGRESS for September, page 90, and is really more of a criterion of the "flowing" quality of the sheet than is a value for the elongation.

It is also fairly well established that the elongation varies with the dimensions of the test piece. Sheet steel is a low-carbon steel and, commanding no premium for quality, it cannot be highly refined. There are apt to be small areas of sulphide or dirt inclusions whose effects would be more pronounced in a ½-in. wide specimen than in a 3-in. specimen. Is it not then somewhat fallacious to derive a standard



Courtesy Pratt & Whitney Co.

of quality of a sheet, measuring, say 36x75 in. from a tensile specimen measuring $\frac{3}{4}$x8 in., especially when the most severe draw on this particular sheet is probably toward the end of the sheet where the damaging inclusions are the least likely to occur?

In summation of the foregoing: It is not enough to state a plain figure in any test, even though qualified by the words "max" or "min," as it does not indicate the relationship of the properties of the specimen tested to those inherent "flow" properties which are desired.

The author's experience leads to the following conclusions based upon tests performed on material during and shortly after the finish of the processing:

Rockwell hardness test is very consistent and shows markedly the agreement or deviation from the ideal of the specimen tested, when the chemical composition is known. It is rapid and allows of a comprehensive exploration. Check blocks for all ranges of hardness allow quick verification of the accuracy of the machine. The liability for personal error is small.

When the Erichsen machine is in correct condition, results can be obtained consistently with only about 2% variation, but the softening effect of annealing after normalizing is not demonstrated as definitely as with the Rockwell. However, unaccountable variations have been encountered in the depth and shape of the cup with the machine in apparently perfect order. The Erichsen test does show a difference in flowing characteristics of sheets but the numerical values do not change much for a big difference in workability in the sheet.

The machine has been manufactured with certain arbitrary contours as regards the tool and the back and front dies, and one wonders how to determine when the machine has developed enough wear to make the results obtained appreciably at variance with those from a standard machine, especially as to alignment.

If it can be safely assumed that the machine is accurate, this test is very useful inasmuch as a sheet can be explored very easily. The time required to make a test is very small.

As to elongation: A larger variation in figures for elongation can be found from the same sheet where everything should be the same than in the preceding tests. Also, if several sheets be taken from the same part of an ingot and processed identically, quite a difference can often be found in the corresponding elongations; one would average 33%, the other 38%. Both values would be classified as good, but such variations preclude the use of this test for evaluating the efficiency of the mill treatment. It is also an every-day occurrence that sheets with a big variation in Rockwell values have the same elongation.

Most Useful Test

The best combination of tests would be a chemical analysis and the Rockwell hardness of the specimen examined (when the inherent relationship between the above two factors of an ideally annealed sheet has been established), if other factors did not assert themselves before the sheet is fabricated, namely, cold rolling and subsequent aging.

It is generally assumed that cold working increases the elastic limit, yield point, and ultimate stress. This is undoubtedly true for a considerable amount of cold work after the specimen has fully aged. But what happens with small reductions, which is the practice for extra deep drawing sheets? The table on page 57 shows the properties found in a sheet split longitudinally, one half tested in the annealed last condition (showing stretcher strains at the yield

	Annealed Last		Cold Rolled Last	
	Transverse	Longitudinal	Transverse	Longitudinal
Yield point	31,000 lb.	30,000 lb.	27,000 lb.	27,500 lb.
Ultimate strength	48,000 lb.	49,500 lb.	49,500 lb.	48,500 lb.
Elongation in 8in.	35%	35%	35%	35%
Elongation in 2in	56%	56%	57%	56%
Erichsen	10.80mm., 10.90mm.	11.30mm., 11.30mm.	11.10mm., 11.10mm.	11.30mm., 11.20mm.
Rockwell	B42, B43	B42, B40	B43, B43	B43, B41

point) and the other given enough cold rolling to avoid such strain markings. The anticipated increase in strength and hardness and reduction in ductility do not appear; the biggest variation is in the yield point, which decreases rather than increases.

The above table represents the values we would expect to get after enough cold rolling to insure against stretcher strains for about one month. If it is anticipated that a longer period will elapse before the material is to be used, a correspondingly greater amount is done, which will show an increase in the yield point and a smaller increase in the ultimate strength, but it takes a great deal of cold rolling to raise the yield point to a figure equal to that in the annealed last condition.

These figures will probably be accepted with reservations by many due to the fact that in most cases the time element is never taken into consideration in testing cold worked metal. The figures quoted refer to tests made on the same day the cold work was performed.

An approximate relationship has been found by the author between the yield point and the ultimate stress according to the final operation as follows: After normalizing, 70%; after normalizing and annealing, 62 to 65%; after normalizing, annealing, and cold rolling, 50 to 55%.

Aging of Steel Sheets

Aging is a peculiar property of *some* steels which has had to bear the onus of many unsatisfactory performances due to unknown causes. Very little is known precisely about it and the sooner something is found, sheet steel manufacture and use will be much simplified. Two things which determine whether aging will take place and its extent are apparently

(1) Some factor inherent in the steel

(2) The deformation to which the steel has already been subjected.

In the experiments performed by the author upon this subject three methods of testing were used; tensile, Erichsen, and Rockwell, and it was found that the test values for subsequent intervals (first tests were made on the same day the cold rolling was performed) either remained constant or decreased. In but a few instances they increased.

It was considered that the personal error on manipulating the tensile machine was too great to follow any changes due to aging, yet within two days a noticeable change had occurred in the yield point. The ratio of yield to ultimate strength increased gradually until it approached what would be expected of a straight normalized steel sheet.

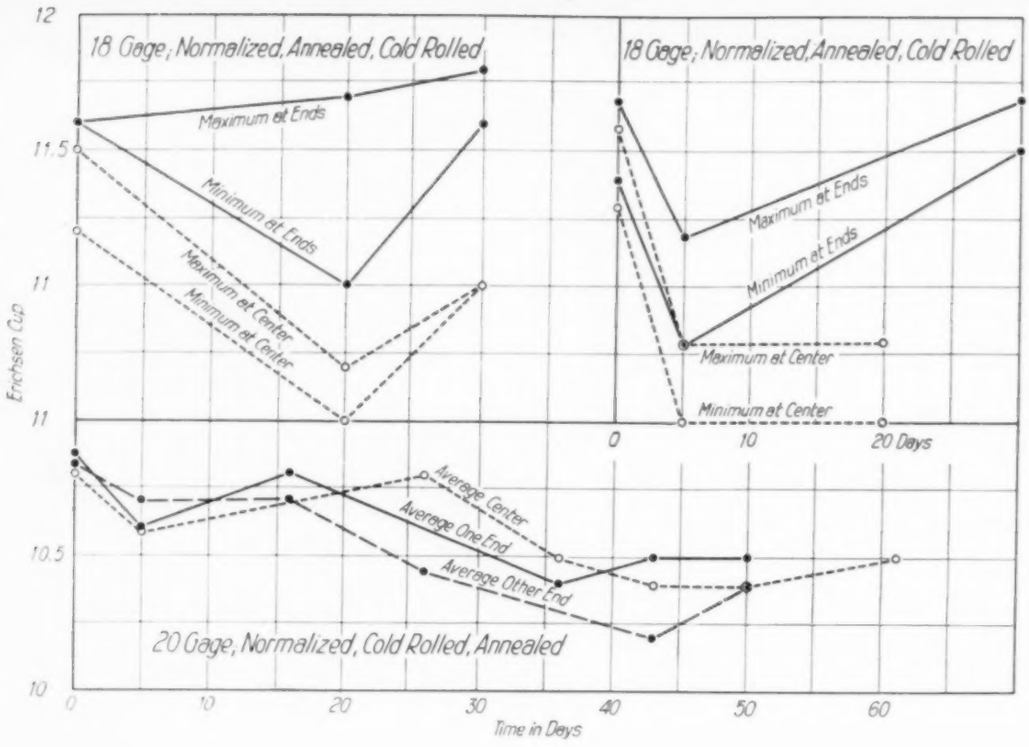
Only where a great deal of cold work was performed was there a very appreciable decrease in elongation with aging.

Notwithstanding some unaccountable variations in the Erichsen test at various times, it was preferred to any other to discover the effect of aging upon the ductility of sheet steel. A machine direct from the factory was used in the tests. Representative results are plotted in the adjoining figures.

Summarizing the facts found in these tests:

(1) No correlation could be found between the variations of mill cold rolling and the subsequent aging.

Photograph at Indiana Harbor Plant, Youngstown Sheet & Tube Co.



decrease for that piece was reached, though not the maximum for all, then an increase occurred until the original was reached.

(7) The rate of change varied with the sheet.

(8) While stationary values were found mostly from the same heat, stationary and decreasing values were sometimes found in sheets from the same heat, and in sheets having same or different amounts of cold working.

(9) Rockwell values varied and to the same extent as the Erichsen, but in no constant relation. Many times the Rockwell hardness of a given sheet remained practically the same while a large variation was occurring in Erichsen.

(10) A very low-carbon heat showed as much decrease in Erichsen as a high-carbon heat; a sheet from the bottom of an ingot showed a 10% decrease in test value.

(11) The most consistent changes in test figures occurred in samples from the center of sheets. This might indicate that segregation products were responsible.

Upon considering all the tests, the author would say that of the two factors, the steel and its deformation, the steel is fundamentally the controlling factor.

On the assumption that nitrogen is the cause of age hardening, a heating to 1,110 to 1,290° F. would put the nitrogen into solution, and if no subsequent deformation occurred there would

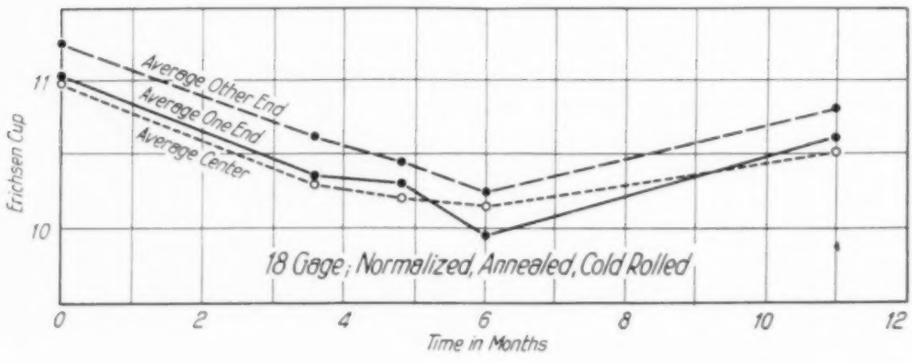
(2) About 15% of the sheets showed no variation in Erichsen value in a period of 3 months, about 5% showed a slight increase, and the remaining 80% showed a decrease ranging up to about 12% of the original value.

(3) The center of the sheet which contained the most chemical segregation showed the biggest proportional decrease. In general, the ends and center of sheets did not behave the same — the center could decrease while the ends remained constant, or while one or both ends decreased.

(4) The amount of decrease in Erichsen value was not uniform, some sheets decreasing only a small amount while others reached the 12% mentioned.

(5) Decrease in test value occurred earlier in some sheets than in others even though the minimum was eventually reached by both.

(6) After a certain period of maximum



Diagrams Represent the Way the Ductility of Sheet Steel (as Measured by Erichsen Test) Varies With Time

be little or no subsequent precipitation (and therefore hardening). However, if such a steel was deformed either before or after annealing followed by slow cooling, as in sheet steel manufacture, nitrogen precipitation will occur.

In connection with this reasoning it is interesting to note that the steel which maintained most nearly the same value during aging was the "normalized only" specimen, followed by cold rolling.

Thus, it would seem that to avoid age hardening a normalized only sheet is desirable, with no box annealing to eliminate the slow cooling factor. This naturally would give a much stiffer sheet than a box-annealed sheet, but the question still remains whether the box-annealed sheets would, by age hardening, become as stiff as the normalized only sheets. The experience of the author is that a normalized only sheet will not perform as well as the usual type.

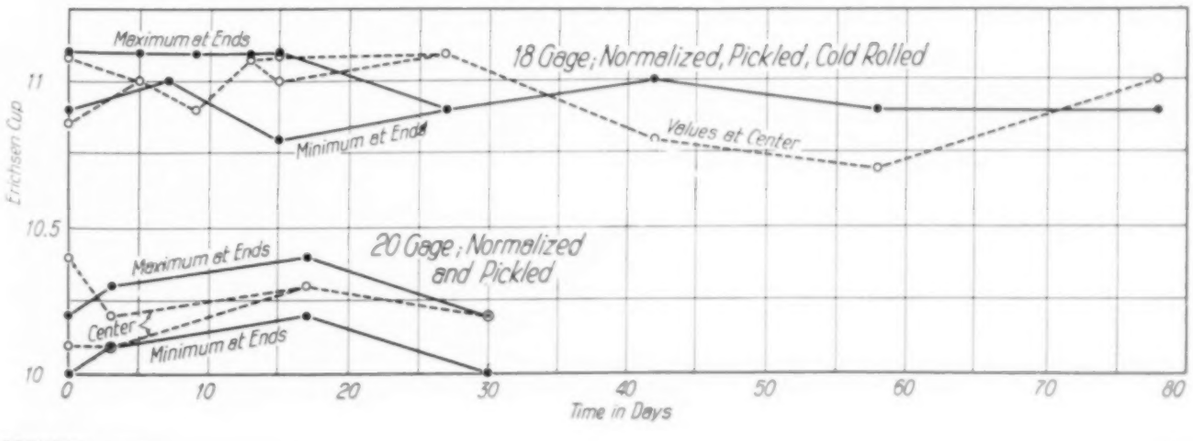
Although the question of whether it is nitrogen which is the cause of age hardening is open to more definite proof, it seems that it is caused by some element present in the steel. Some heats of steel used for deep drawing sheets do not age harden, and at the present time sheets are being made which will perform the most difficult stampings, even though age hardening has taken place. These sheets may have initially so much ductility that they still have the necessary ductility after the lapse of time.

Before summarizing, consider the table above. The sheet under study was normalized, annealed, and cold rolled, the latter operation being somewhat more drastic than is usual in an attempt to accentuate eventual properties, and then tested at a later date.

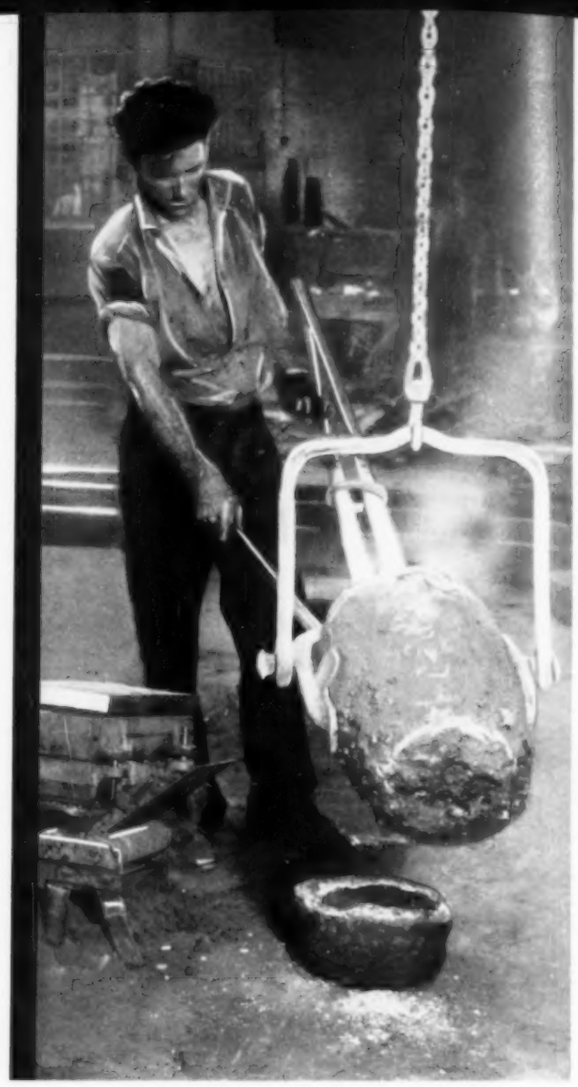
	Transverse, Across Center	Longitudinal, Center to One End	Longitudinal, Center to Other End
Tested One Week After Cold Rolling			
Yield point	35,000 lb.	36,000 lb.	37,000 lb.
Ultimate strength	53,000 lb.	55,000 lb.	55,000 lb.
Elongation in 8 in.	33 %	32 %	23 %
Erichsen	10.30 mm., 10.60 mm.	10.50 mm., 10.60 mm.	10.60 mm., 10.70 mm.
Rockwell	B 57, B 57	B 55, B 54	B 55, B 54
	No strain	No strain	No strain
Tested Two Months After Cold Rolling			
Yield point	37,000 lb.	38,000 lb.	38,000 lb.
Ultimate strength	56,500 lb	55,000 lb.	58,000 lb.
Elongation in 8 in.	26 %	24 %	22 %
Erichsen	9.50 mm., 9.60 mm.	9.60 mm., 9.80 mm.	9.30 mm., 9.70 mm.
Rockwell	B 57, B 57	B 57, B 57	B 55, B 54
	No strain	No strain	No strain
Tested Fourteen Weeks After Cold Rolling			
Yield point	37,500 lb.	40,000 lb.	37,000 lb.
Ultimate strength	57,000 lb.	56,500 lb.	57,000 lb.
Elongation in 8 in.	30 %	27 %	20 %
Erichsen	10.00 mm., 10.30 mm.	9.80 mm., 10.00 mm.	9.90 mm., 10.00 mm.
Rockwell	B 59, B 58	B 56, B 57	B 56, B 54
	No strain	Shallow strain	No strain

From the mill metallurgist's point of view it may be said that each test can be used to check mill practice, but several days after final processing their respective values as a means of evaluating the qualities of sheets are debatable. A consideration of the second table tempts the author to suggest that if a consumer wants to have some test he might as well take his choice of tensile, hardness or cup.

Age hardening is a fundamental property of this class of steel and yet it has apparently received very little study in respect to sheet steel quality. Since the steel itself governs this phenomenon, it would seem that the first step to govern sheet steel properties would be to find out how to control steel making so as to avoid this phenomenon. By cooperation between steel maker, sheet maker, and consumer a more thorough understanding of these properties can be obtained which will lead to much more economical operations to the latter two especially.



By R. D. Bean
Chief Engineer
Brown Instrument Co.
Philadelphia



Ladle Heat

measured quickly and accurately

EVERY foundryman engaged in the production of non-ferrous castings has become well aware of the importance of pouring his metal when it is at the correct temperature. Pouring temperature has much to do with the avoidance of porous castings, assurance of maximum tensile strength, and the reduction of miss-runs. It has been stated by Wolf and Romanoff of Ohio Brass Co. that "no single operation has more influence in determining the quality of ultimate finished product than pouring at proper temperature." They quoted figures before a meeting of the American Foundrymen's Association for a brass which was hot poured to a casting having an ultimate tensile strength of 16,300 lb. per sq.in. and an elongation of 7.5%, whereas a duplicate casting from the same ladle of metal, after it had been cooled 100° F. by adding small gates and sprues, tested 27,500 lb. per sq.in. and gave an elongation of 14.6%.

Metal poured too hot contains much gas in solution, which reappears in bubbles during solidification — blow-holes trapped between crystals of solid metal, causing porosity and brittleness. Oxides and impurities are also carried into the mold in a fluid or plastic condition, making dirty castings, dirt which would have risen to the surface of the ladle and been skimmed off the metal at a lower and a proper pouring temperature. Finally, hot metal scours the sand in the mold.

Consequently, it is an adage of sound foundry practice that the metal should be

poured as low as possible. Yet, up to 1920, foundry literature is almost bare of notes about means whereby this desirable point can be measured. Long accounts of "modern" foundries appeared in print, telling much about every other detail of the practice; temperature control was still left to the skilled workman.

Crude Methods in Past

Various crude means of measuring molten metal temperatures have been used in the trade since time immemorial. These include such stratagems as thrusting a quill of paper into the molten metal and withdrawing it quickly. This is a favorite method of the old-time typefounder, who, by observing the degree to which the paper scorched, was able to estimate roughly whether or not the metal was at the right heat. If the paper burst into flame or was badly charred the metal was too hot. But if it were simply scorched brown the metal was considered to be just right for pouring.

In galvanizing tanks, the operator frequently would throw sawdust on a skimmed portion of the zinc bath, gaging the temperature from the way it would smolder.

Brass and aluminum foundrymen ordinarily depended on the color of the hot metal. Sometimes he would heat his brass to the boiling point of the zinc and, drawing it from the furnace, thrust a bar into the boiling mass. By holding one end of the bar he was able to feel the vibration set up by the boiling, and when the vibration stopped he would pour the metal.

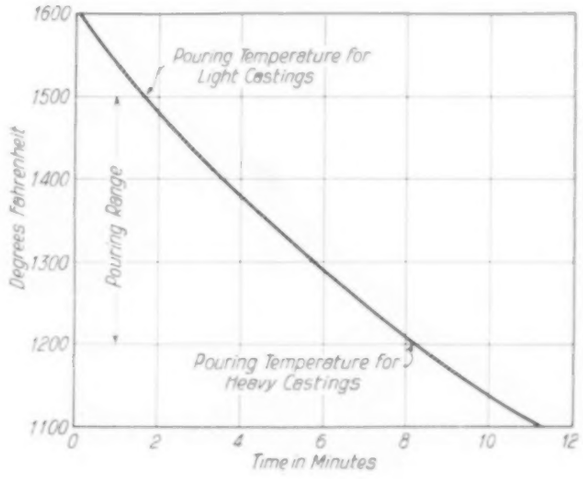
It is universally realized, of course, that the color of the metal depends upon the analysis and upon the amount of light within the shop. Skilled foundrymen, therefore, also observe the viscosity or fluidity of the metal, to check the estimate from color. Viscosity is gaged both by sight and by feel — by the flatness of the surface, the flotation of dross, by the way it pours, and by the way it adheres to the cold mold or a cold skimmer bar. Here, again, the indications vary with the analysis of the metal, and while they are used almost instinctively by a first-class foreman, the ordinary workman who is molding castings of various sizes and in various alloys cannot estimate the temperature closer than 50° F. plus or minus. The figures quoted at the outset indicate just how badly such an error would affect the quality of the product.

Scientific temperature measuring equipment has been available for many years; but the special problems of the non-ferrous foundry have caused its rapid adaptation to be delayed much behind the applications to other branches of metallurgy. These special problems are outlined as follows:

The equipment must be portable. In heat treatment departments, the electrical indicators can be mounted rigidly in protected places. In foundry work the temperatures must be taken at various places on the floor, or else the ladles and crucibles must be routed past a certain station in a busy shop. In either plan the equipment must be much more rugged and foolproof.

The readings must be taken rapidly. In heat treating furnaces the fluctuations in temperature are designedly suppressed. The diagram herewith shows a typical cooling curve of the molten metal in a crucible of aluminum after removal from the furnace. Within the usual pouring range, the metal in the crucible cools at the rate of 40° to 50° F. per min. This graph clearly shows the importance of speed in getting a temperature reading if the metal is to reach the mold at a correct heat. This speed necessitated a type of thermometer that would be sufficiently protected to be enduring in service, yet be so constructed as to assure rapid

It Takes About Six Minutes for a Crucible of Aluminum to Cool Through the Ordinary Pouring Range



transfer of heat from the bath to the instrument, thus obtaining an accurate reading before the metal would have time to cool materially.

The metal slags over rapidly or smokes. Smoke prevents accurate readings by optical pyrometers; a slag or oxide scum would obscure the clean metal from view. If a closed-end tube is inserted into the metal, so an optical pyrometer can be sighted on the bottom through unobscured atmosphere, the tube takes so long to come to the temperature of the molten metal that the requirement of speed, noted just above, is violated. This leaves the thermocouple pyrometer and indicator as the acceptable alternative for accurate estimation.

Hot Metal is Corrosive

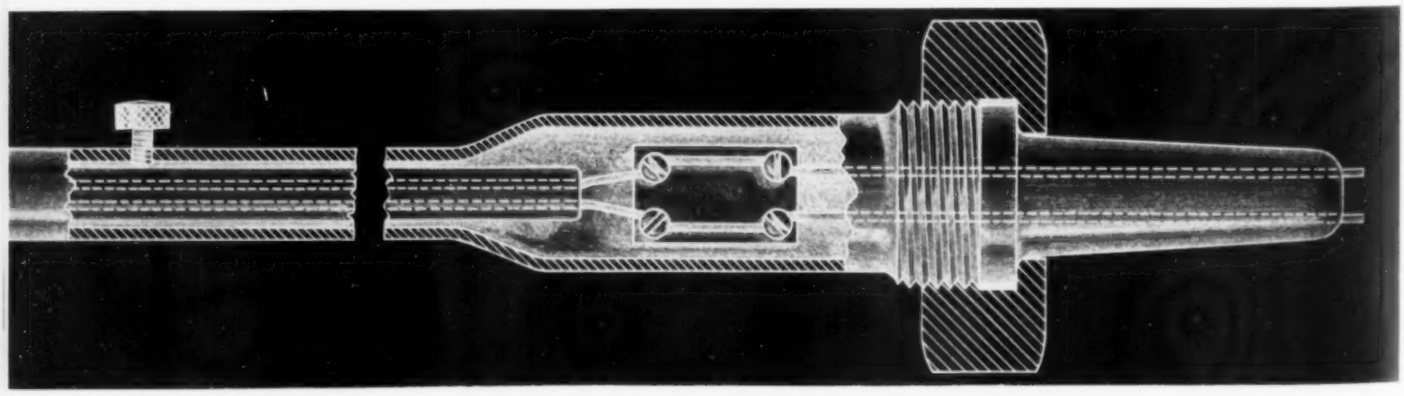
The hot metal is corrosive. This is especially true of phosphor bronzes and of brasses and other copper alloys (due to the high pouring temperatures — 1,700 to 2,050° F.). This means that the thermocouple wires (if bare) or the protection tube must not alloy with the hot metal, must not accumulate slag which would appreciably reduce the rate of heat transfer, and yet must be cheap enough so that the unavoidable wastage will not boost the cost of thermocouple maintenance too high.

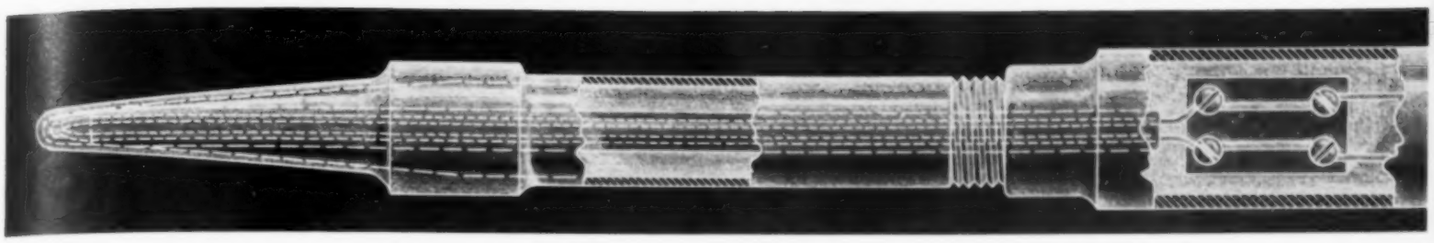
The indicator should be easily read. This means that the work can be done by a person of ordinary intelligence after a moderate amount of training. An important factor in getting accurate readings is the type of indicating pyrometer employed. Since with some metals, aluminum for instance, a small difference in pouring temperature makes a great difference in the quality of castings obtained, the operator must be able to read accurately and quickly small temperature differences on the dial of the instrument. As the temperature of a molten copper alloy may be as high as 2,300°, it is obvious that with an instrument having a small dial it would be difficult to read a small temperature difference. In other words, it is useless to try to read temperatures quickly and rapidly within 10° on a scale where a 50° division may be only $\frac{1}{16}$ in. wide. Furthermore, it is necessary that these open-scale instruments should maintain the accuracy and sensitivity which the open scale implies.

A symposium by the American Foundrymen's Association in 1926 presented the practical methods then used by about 20 important foundries to solve the above problems. At that time opinion favored the bare fork type of couple for brass and the protected welded junction for aluminum.

Brass foundrymen had found, for instance, that relatively heavy couple wires could be used without protecting tubes and even without welding a connection at the hot end. No. 2 or 4 gage alumel and no. 6 or 8 gage chromel were found suitable (the heavier alumel was used because this alloy dissolves more rapidly in the hot brass); they can be insulated from each other in a cane, with 2 or 3 in. of bare wire projecting from one end. The other end would be connected through suitable leads, compensating for cold end correction, to a millivoltmeter with dial calibrated to read temperature.

Thermocouple for Aluminum Foundries Uses the "Ever-Sharp" Lead Pencil Idea of Feeding Wires Forward as They Are Corroded Away by the Hot Metal





Brass Is so Corrosive That a High Alloy Protection Tube With Thin Walls Protects the Thermocouple Wires and Hot Junction

When the bare ends of the couple wires — perhaps ½ in. apart — were submerged in the molten metal, they quickly were heated to the temperature of their surroundings. Molten metal provided a short circuit for the electricity generated at the hot end, and served the same purpose as a weld between wires at the hot end.

By this means the pointer would reach a steady indication within a few seconds. However, the temperature registered was the temperature of the surface of the metal in the ladle, less a certain amount representing the amount of heat which was conducted back along the heavy thermocouple wires. To correct for this, the skilled operator withdrew the immersed portion slowly; as the tips broke contact with the surface the surface temperature was read.

Bare wires of this sort have certain defects in hot alloys. In the first place, they must be brushed free from slag, and most of them are quite brittle at operation temperatures. In the second place, the action of hot zinc oxide is liable to change the electrical characteristics so that the indications are erroneous. Alloying with the hot metal acts in a similar way. Lastly, the wires waste away within a hundred immersions more or less, and must then be replaced or cut back.

Fluctuations in readings, from these causes beyond the control of the operator, are so pronounced that it was recommended at the Foundrymen's meeting previously mentioned that a laboratory man with a standard thermocouple visit every pyrometer station twice each shift and read a metal temperature in the same ladle simultaneously with the one in constant use. If a difference of more than 10 or 15° was noted, a new thermocouple should be provided.

In that symposium similar methods were noted to be quite suitable for aluminum. Owing to the lower temperatures of operation, No. 8 gage wire could be used, and it could be used with bare ends, as noted above, for about 300 readings before the ends needed to be cut back.

The conditions described in the foregoing have been studied for some years by the Brown Instrument Co., Philadelphia, in view of the great need of the industries using non-ferrous molten metals for more suitable temperature measuring equipment. These studies have led to the development of two new types of molten metal thermocouples.

Bare End Thermocouple

For measuring the pouring temperatures of molten aluminum the Brown Co. has adopted the bare-end couple described above. Completely assembled, this new device is shown in the figure. It consists of the thermocouple wires mounted inside an operating handle in such a manner that the wires can be fed forward through perforations in a replaceable refractory tip. When the thermocouple is thrust into the metal, the refractory housing penetrates the slag so that the hot junction of the couple is formed in the clean molten metal itself, thus assuring a quick and accurate measurement of the metal's temperature below the surface.

As the molten aluminum consumes the exposed ends of the wires in service, more wire is fed to the tip by advancing the sliding button.

Tests show that it never requires more than 1 sec. to produce a settled, steady instrument reading. A large instrument dial permits an accurate reading within close temperature limits, and these temperatures are of the hot metal deep in the crucible — not merely the surface temperature — because the thermoelectric circuit is completed by the molten metal itself, down below the slag line. *(Cont. on p. 104)*

A Photograph by John P. Mudd
for The Midvale Company

FROM THE PRESIDENT TO THE MEMBERS

ONE YEAR AGO, the first issue of METAL PROGRESS was published by authority of the Board of Directors. It is fitting at this time for us to review its accomplishments during the past twelve months. From the start, it has maintained such a high standard of excellence that it set the pace for other technical publications.

Twelve issues have indicated that our expectations have been realized. The contents have been clearly defined by the name chosen; manufacturing processes, heat treatments, properties of metals, their fabrication and applications, and welding have all received attention. Not only iron and steel, but aluminum, copper and their alloys have been considered.

Accounts of metallurgical activity not only in this country but also abroad have been brought to the attention of the members, thus rounding out the issues so every member can find something of interest and value each month.

For several years, the Board of Directors had recognized the fact that a steadily increasing number of executives and production department heads were joining the society, men who do not spend all of their time on metallurgical problems, but who have a very decided interest in new developments of raw materials, processing methods and heat treatments. To these men, METAL PROGRESS has been a source of reliable and up-to-date information.

Our advertisers have been enthusiastic concerning the make up of the magazine, the quality of the paper used and the artistic manner the illustrations and reading matter have been balanced.

I am sure that the whole-hearted assistance which the editor has received from you in the past will be continued. Without this he will be unable to maintain the high standard that has been set in the published manuscripts. It is your magazine; you may well be proud of it, for it is carrying forward the American Society for Steel Treating tradition of leadership.

Beginning November 15, we will resume the publication of TRANSACTIONS. This will contain the highly technical and scientific papers presented at the annual convention with the discussion, and such other technical papers as the Publication Committee may deem of sufficient merit for permanent record. The TRANSACTIONS may be returned for binding as previously.

The REVIEW will be continued. This contains the current news of chapter activities, detailed minutes of the meetings of the Board of Directors and all national and chapter records that are of interest to the membership at large.

Surely with the three publications, METAL PROGRESS, TRANSACTIONS and REVIEW, The American Society for Steel Treating may justly be proud of the service being given to its members.

J. M. Watson

PRESIDENT

Why Not Use Vacuum Tubes in Pyrometers

WHEN VISITING research laboratories one notices that vacuum tubes are hitched to testing equipment in a variety of ways. Frequently, they are used with sensitive electrical bridges, and can then detect the flow of an almost infinitesimal current, thus indicating immediately any lack of balance between the opposing circuits. Remembering that thermocouples depend upon the generation and measurement of very small electric currents, one wonders why there has not yet been devised and marketed some pyrometric equipment utilizing vacuum tubes. It would seem that in this manner the small potentials generated at the hot junction could be amplified to any desired degree, and produce a current strong enough not only to swing a recording needle but also to operate recorders and even open and close fuel valves or illuminate signals.

Looking a little deeper, however, one finds that the familiar radio tube is at its best when magnifying minute alternating currents, whereas the electrical flow from a thermocouple junction is direct. Also that while it is a sensitive instrument, it is not precise. Amplification of small direct current, while not impossible, is not nearly so easy, and at the present state of knowledge requires apparatus and hook-ups entirely different from the familiar circuits used in radio sets. Especially would it be necessary to guard against slowly varying disturbances, such as drifting of supply voltages and changing tube characteristics.

It must also be said that while the e.m.f. of a thermocouple is low, its internal impedence is also small, so it produces sufficient current (power) when operating in the ordinary metallurgical ranges to deflect a rugged galvanometer and an indicating needle. It is also necessary to remember that high temperature measurement requires two essentials — the thermocouple and the measuring instrument. Granted that the best of our present measuring instruments have considerable inertia, it is also true that instrument makers have successfully and for years marketed equipment which is considerably more accurate than the best thermocouples available. Therefore it would seem that the direction for improvement is toward thermocouples and auxiliaries with a higher degree of reproducibility rather than toward more sensitive indicators, and any application of vacuum tubes would probably have to be marketed on the basis that they would do something that available equipment cannot do, such as extend the range or increase the sensitivity at unusually high or excessively low temperatures, or remove some other limitation such as the necessity of having a hot junction attached to stationary objects. Undoubtedly, distinct future possibilities lie in these directions.

It is well understood, of course, that the recording and controlling equipment (especially the latter) is not actuated by the small currents or potentials generated at the hot junction, but by auxiliary devices, driven by an independent source of power. The problem met by the designers has consequently been to devise mechanical amplifiers for small electric flow. They have evidently been able to do this, and it is about all that a vacuum tube can do. Even though some sensitivity may be lost in the process of mechanical amplification, the net result is an accuracy ample for commercial requirements, and as noted above, better than the accuracy of the various auxiliaries now in use.

If a small current be amplified by vacuum tubes before it is measured, it will obviously be necessary to insure that the ratio of magnification be exactly known and be unchanging. This is a far more difficult feat than merely detecting an infinitesimal current and magnifying it to some unknown amount sufficient to indicate its presence unmistakably. Yet it is a *quantitative* measurement of current or e.m.f. which is necessary in high temperature work.

These statements regarding the practical sufficiency of available recorders and the diffi-

culty of substituting precise electrical amplification should not obscure the fact that considerable work is being done constantly by leading instrument makers to explore the possibilities. Indeed, some commercial applications have already been marketed.

Photo-electric cells have been recently adapted to this problem of recording the movements of a sensitive galvanometer needle, and even using it to control valve motions absorbing considerable power. In these devices the recording pen and other control equipment is driven by separate high-torque elements, kept in step with the swinging galvanometer needle or an attached mirror by an optical system, a beam of light, and photo-electric and pliotron tubes. It is obvious, however, that this is not an attempt to amplify small direct currents; it is merely an optical and electrical magnifier doing what is now being done by mechanical arrangements in our familiar temperature control equipment.

Another promising direction of advance is the perfection of a direct current amplifier which will entirely eliminate the galvanometer. Grid-glow tubes have already been used in this manner, in an experimental way. For some purposes — namely, where *instant* response to a change in impressed voltage is necessary — it appears to have distinct advantages, and will undoubtedly receive much more attention by practitioners in the future.

Design for Welding Requires Real Skill and Engineering

AN INCREASING amount of printed material is being put into circulation which purports to explain the problem of "design" for welding. It has much to say about unit stresses and the strength of a weld in shear per linear inch, and contains sketches showing interrupted welds, implying that it is not necessary to weld many joints from end to end.

If this information gets into the hands of engineers and designers who can use it with discretion, well and good. They need it. Especially is it necessary to educate the educators, the professors of machine and structural design, who for lack of better are using textbooks published 20 years ago, when welding was a rough-and-ready repair method.

The danger is that some half-baked ironworker and some half-educated draftsman will take this elementary information and some other hand-book data and convince themselves and some unfortunate customers that they can make anything from a motor base to a highway bridge cheaper, better, quicker and lighter by welding. It is the old, old problem of preventing damage to a new process by its over-enthusiastic believers and practitioners.

Seldom will it be found economical to take the drawings of a riveted structure and say "For each rivet we will put in a 1-in. weld." Nor will there be much profit in reproducing a steel casting out of bits of plate, angle iron and I-beams. In the first instance, structural design has been developed by many years' experience with the riveting process — machinery has been developed to do the work efficiently, and the design is not directly adaptable to other methods of joining. In founding practice (the second instance) the actual requirements of the structure have been modified by the limitations of the molding and core making, and the ability to put hot metal into cavities in a way that it will solidify into a sound strong unit.

New and searching studies are necessary to find out what parts of such old designs are really essential and what portions have been added as conveniences or necessities for the conventional method of construction. When this separation of essential and non-essential has been made, more skill, ingenuity and sound judgment will be needed to supply the bare essentials (without the excrescences) with a new jointing method.

Certainly it is a job which cannot be done in the ordinary welding shop without the guidance of expert engineering.

By D. A. Holt, Ph.D.
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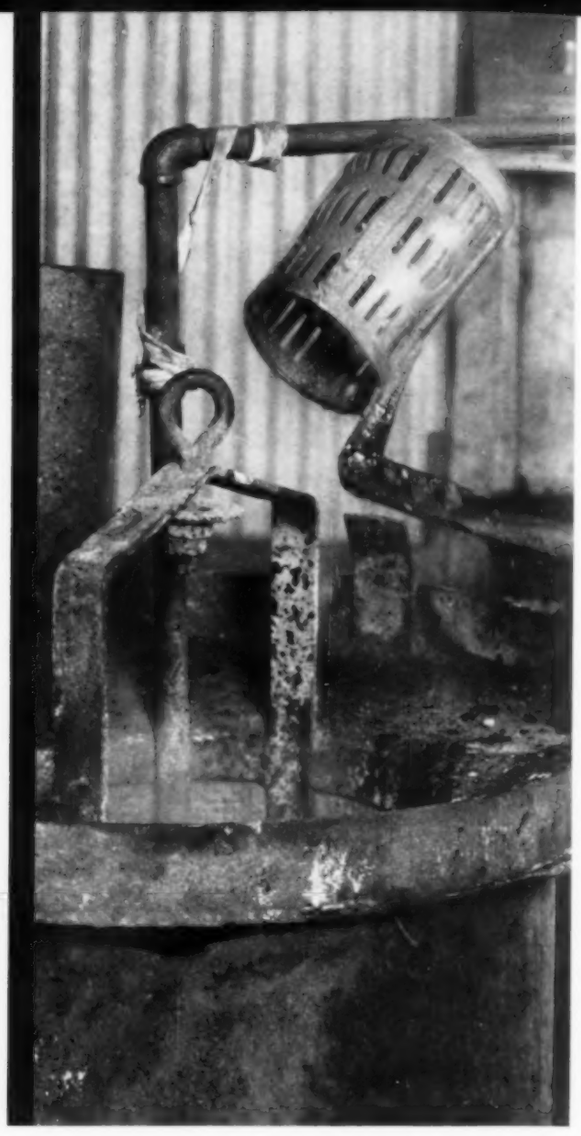


Cyanide Heat for alloy steel

AT THE PRESENT TIME the cyanide bath is used extensively for reheating plain and alloy steels, principally before quenching. In spite of the widespread utility of the method, little information on the essentials of the action has been printed. Most metallurgists regard it as a salt bath for effectively excluding atmospheric action on the hot metal, or a bath which will give a superficial skin of hard metal if the part remains immersed for any considerable time.

An attempt will be made, therefore, to show that the many applications of this heating method, especially numerous in gears of highest quality, are justified by a group of solid advantages. It may be said, in fact, that the cyanide bath offers in one medium no less than seven major advantages, as follows:

1. It develops on the surface a very hard, wear-resistant case, which contains both carbon and nitrogen.
2. Case depth is simply and accurately controlled.
3. Highly finished surfaces are maintained perfectly throughout the treatment.
4. Quenched parts have an attractive surface color.
5. Adhering traces of the salt can be easily

removed from the work after the quenching operation.

6. It has a reasonable cost of operation and maintenance.

7. It does not corrode the work during treatment, nor does it have a tendency to accelerate corrosion afterward.

It is small wonder, then, that steel parts are generally heat treated in cyanide baths to obtain one or several of the above advantages. Of the cyanide treatments applied to a large variety of work, the following are typical:

Reheating of automotive gears to increase their wear resistance. This is the largest single use of the cyanide reheat; the greater part of the transmission gears now made in this country are treated in this manner.

Reheating high grade alloy steel nuts and bolts to harden and therefore prevent burring when tightened up with a wrench.

Drawing high speed steel tools to increase their hardness.

Heat treating alloy steel parts, such as wrenches, to prevent nicking or denting.

Turning now to the heat treatment of gears: There are three different methods of operation, *(a)* the cyanide dip, wherein the work is preheated in an appropriate furnace to the quenching temperature, moved for approximately 15 sec. through a cyanide bath held at the same temperature, then quenched; *(b)* the cyanide wash, wherein the work is treated as in the cyanide dip, except that it is held in the bath for one to two minutes, and *(c)* the straight cyanide reheat, wherein the work is heated in the bath from room temperature until it has reached the bath temperature or until the desired depth of case is produced, and then quenched.

These variations in treatment are due to the differences in design and requirements of the gear and composition of the steel used.

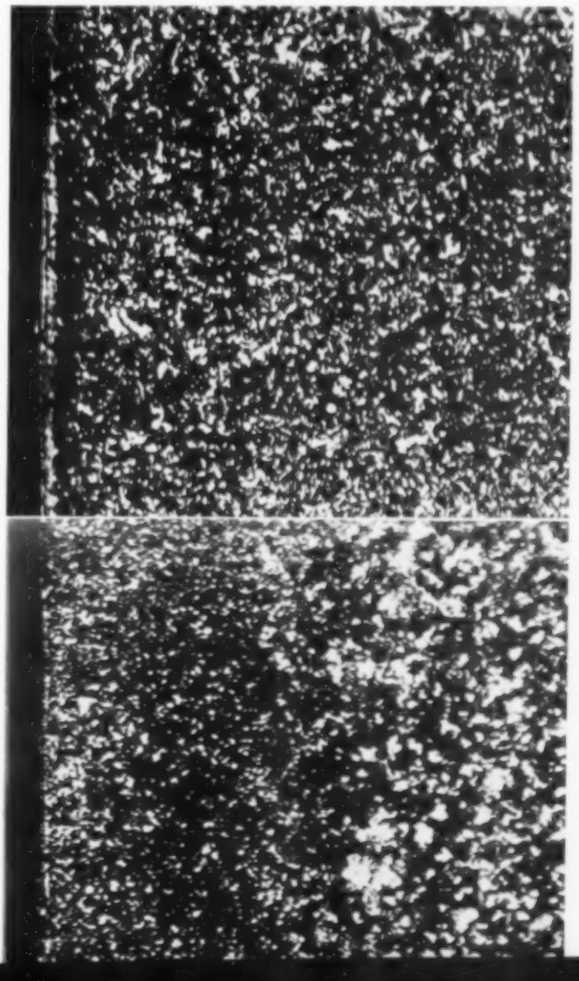
For instance, reliable dynamometer and road tests have shown that the short-time cyanide heats increase the life of transmission gears to from three to five times that of gears made of the same oil hardening alloy steel but hardened by the ordinary air reheat and oil quench. Straight cyanide reheat similarly gives a tenfold increase in wear resistance to transmission gears.

The exact treatment should also be scheduled after a consideration of the tooth pitch and impact resistance of the steel. It is obvious that a hard surface layer on the gear will lower the impact resistance. It should be noted that this effect is independent of the so-called nitrogen embrittlement. Gradients shown later in this article prove that the nitrogen does not penetrate sufficiently deep to affect the properties of the core. Consequently, the time of treatment should be regulated to produce maximum wear resistance with sufficiently high impact resistance to withstand any normal abuse. That the well-designed automobile gear now has this balance is best demonstrated by its freedom from failure and its long life.

Increased wear resistance of the cyanide reheated gears is primarily due to the physical properties of the carbon-nitrogen surface layer which is produced. It is well known that the case is extremely hard when suitably quenched; this is readily demonstrated by means of a sharp file.

Furthermore, the carbon-nitrogen case pro-

Effect of 15-Sec. Cyanide Dip at 1,525° F. Can Be Seen at Surface of S.A.E. 6150 Steel at 300 Magnifications; Fine Grain Extends 0.007 In. Deep After 30-Min. Cyanide Reheat



duced by cyanide treatment is extremely resistant to surface flow. A measure of this resistance is obtained by means of the Rockwell hardness tester. Rockwell-C impressions of cyanide hardened specimens are clear cut; the rim of the impression is in the same plane as the remainder of the surface. This is a certain indication that no surface flow occurred in the metal. No surface cracks can be found, nor is there any spalling around the impression — both evidence that the surface layer is exceedingly tough. In contrast to this, the Rockwell-C impressions on carburized and hardened steels invariably show small raised circular ridges around the impression.

Surface flow is a detriment in highly stressed surfaces such as gear teeth. It is, in fact, a cause of tooth pitting, for surface flow pushes up a certain portion of the tooth above its proper level, and this becomes over-stressed at some point in the revolution. In time this over-stressed portion of metal breaks away from the tooth face, when its endurance limit has been passed, leaving a pit.

One motor car manufacturer after investigation found that a 15-sec. dip completely prevented surface flow, and eliminated tooth pitting. The treatment produced no detectable change in impact resistance of this particular gear; thus, full gear strength was retained and the wear resistance greatly improved.

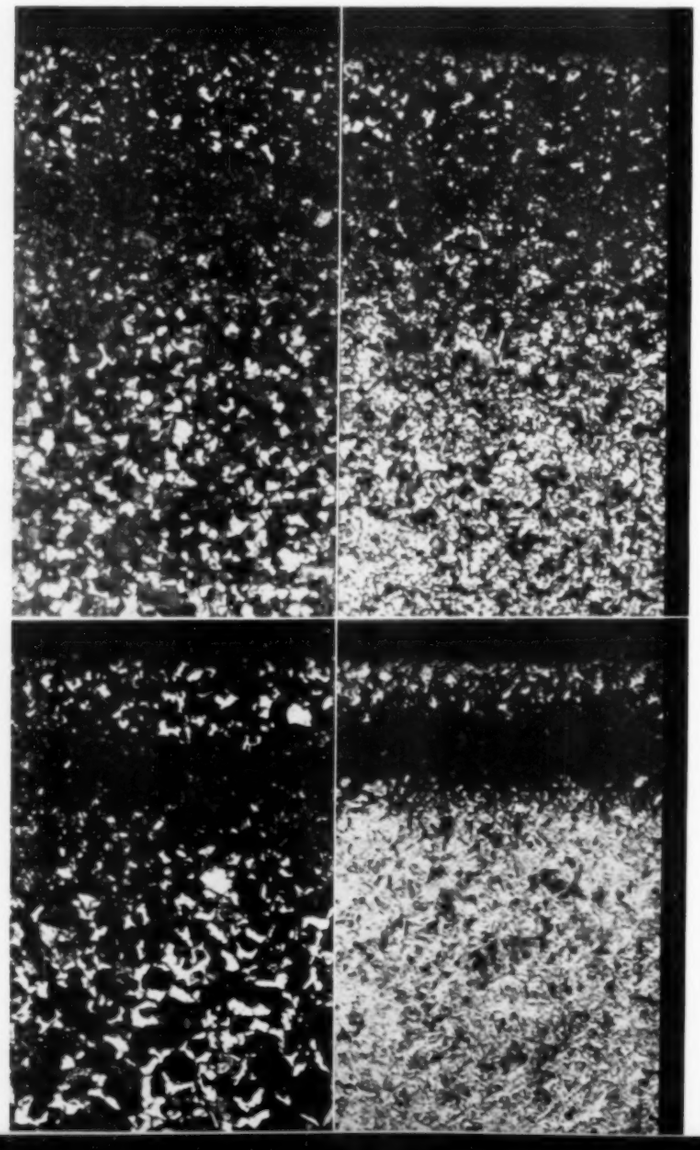
The gradient tables on page 71 show that some of the widely used gear steels absorb a surprisingly large amount of nitrogen during a 15-sec. period in contact with cyanide. Carbon is not increased to anything like the same degree. This nitrogen absorption is probably the reason for the increased hardness and life of cyanide treated gears as compared with gears of the same steel, air reheated, and oil quenched.

Some work was recently undertaken to show the change in composition and structure with depth of various steels after cyanide treating. In these tests, bars 1 to 1⅛ in. diameter by 7 in. long were normalized; the decarburized surface layer was then removed and the bars surface ground. Test bars were then given the typical treatments at the recommended temperatures (indicated in the table). Following the cyanide treatment all bars were cooled in still air and successive 0.003-in. cuts were removed for analysis. (Diameter of bar was reduced 0.006 in. in each step.) Turnings were washed in ether and dried at 140° F. Carbon was determined by the usual combustion methods.

To analyze for nitrogen, the samples were dissolved in 50 c.c. of warm 7% sulphuric acid. Solutions were then distilled in a standard Kjeldahl apparatus using copper flasks and block tin condensers. Resulting ammonia was titrated with standard sulphuric acid using methyl red as indicator.

Cyanide baths used in this research were made up from commercial grades of sodium cyanide (NaCN). Cyanide (NaCN) and cyanate (NaCNO) contents of the bath are stated; the balance consisted of sodium carbonate or a combination of sodium carbonate and chloride.

Grain Structure (at 300 Magnifications) Changed to Various Depths by 30-Min. Cyanide Reheat. Upper left: S.A.E. 4140, quenched from 1,525° F.; upper right: S.A.E. 5150, quenched from 1,500° F.; lower left: S.A.E. 3135, quenched from 1,475° F.; lower right: S.A.E. 3335, quenched from 1,475° F.



CARBON AND NITROGEN PENETRATION

Recommended Hardening Temperature →	S.A.E. 2345		S.A.E. 3135		S.A.E. 3335		S.A.E. 4140		S.A.E. 5150		S.A.E. 6150	
	1,450°		1,475°		1,475°		1,525°		1,500°		1,525°	
	Carbon	Nitrogen	Carbon	Nitrogen	Carbon	Nitrogen	Carbon	Nitrogen	Carbon	Nitrogen	Carbon	Nitrogen
Preheated Steel, 15 Sec. in 30% NaCN and 8.2% NaCNO												
Cut 1	0.54	0.36	0.49	0.20			0.52	0.48	0.54	0.32	0.50	0.38
2	0.42	0.04	0.37	0.08			0.42	0.06	0.50	0.07	0.51	0.04
3	0.41	0.03	0.37	0.04			0.42	0.05	0.50	0.04	0.50	0.04
Preheated Steel, 2 Min in 30% NaCN and 8.2% NaCNO												
Cut 1	0.51	0.53										
2	0.46	0.06										
3	0.43	0.05										
4	0.40	0.05										
Cold Steel, 30 Min. in 32% NaCN and 5.5% NaCNO												
Cut 1	0.55	0.54	0.45	0.72	0.49	0.62	0.49	0.81	0.51	0.69	0.51	0.66
2	0.49	0.06	0.45	0.09	0.50	0.10	0.56	0.11	0.59	0.17	0.59	0.08
3	0.43	0.02	0.38	0.05	0.39	0.04	0.50	0.05	0.55	0.05	0.57	0.03
4	0.41	0.02	0.38	0.04	0.36	0.03	0.44	0.04	0.53	0.03	0.51	0.02
5	0.43	–	0.38	–	0.38	–	0.44	–	0.54	–	0.51	–
6	0.41	–	0.39	–	0.37	–	0.44	–	0.54	–	0.50	–
Cold Steel 30 Min. in 54% NaCN and 5% NaCNO (Scumming Bath)												
Cut 1									0.82	0.75	0.77	0.65
2									0.71	0.10	0.78	0.12
3									0.57	0.05	0.62	0.04
4									0.51	–	0.54	–
5									0.48	–	0.51	–
6									0.50	–	0.49	–
7									0.48	–	0.49	–

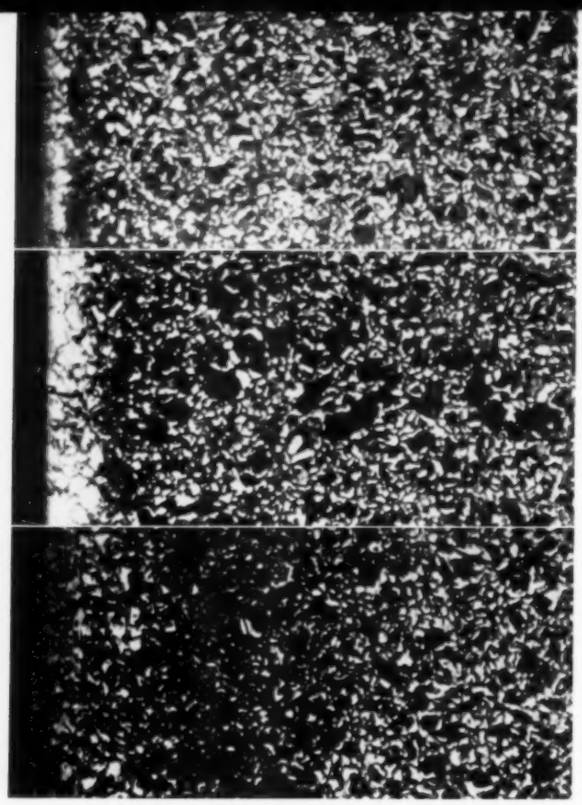
The latter two compounds are inert diluents. Presence or absence of the chloride affects only the melting point and viscosity of the bath. Sodium carbonate is always present, since it is the end product formed by the case hardening reactions in the hot cyanide bath.

Photomicrographs were prepared from portions of the same bars on which carbon and nitrogen gradients were determined. Thus they represent air-cooled sections of the case, etched with 5% nital and magnified 300 diameters.

Examination of the carbon and nitrogen gradients shown in the table clearly indicates that the physical properties of the surface layers of ferrous alloys which have been reheated in the cyanide bath are primarily due to the nitrogen absorbed during the treatment. Carbon absorption is moderate in amount, and the proportion is quite variable, steel to steel. In all samples, however, the surface layer showed the absorption and fixation of large amounts of nitrogen. This remains close to the surface, however. It is probable that the figures for the third cut (0.006 to 0.009 in. below the surface) represent nitrogen existing in the steel bar introduced in the steel making process. As proof of this, a new bar of the S.A.E. 5150 steel used in these tests was sawed across; a 5-gram sample of sawings was analyzed in duplicate, results were 0.046% and 0.043% nitrogen. Similar analysis of S.A.E. 1020 steel showed 0.032 and 0.029% N in check tests.

As might be expected, the preheated steel 15 sec. in cyanide did not absorb either as much carbon or nitrogen as the cold steel 30 min. in the bath. However, even the short cyanide dip will put approximately 10 points of carbon into the surface of the lower carbon steels. Not much more than this is absorbed from the clear baths in 30 min. The longer time, however, permits much more nitrogen to gather in the surface layer and to diffuse an appreciable amount inward. Both the chemical analyses and the photomicrographs prove this.

The carbon-nitrogen cases shown in the micros are characteristic of cyanide treated work, which on quenching develops a characteristic carbon-nitrogen martensite. High nitrogen content in the surface layers of cyanide treated work suggests the possibility of forming a carbon-nitrogen austenite when high-carbon alloy or carburized steels are reheated in cyanide for



Structure of S.A.E. 2345 After 15-Sec. Cyanide Dip at 1,525° F., After 2-Min. Cyanide Wash at 1,450° F., and After 30-Min. Cyanide Reheat at 1,450° F. All at 300 diameters

a sufficient length of time. As a matter of fact, characteristic austenite formations have been obtained by such prolonged cyanide heat treatment. Possible formation of the cyanide austenite does not prohibit the use of a cyanide bath for reheating high-carbon alloy or carburized steels, but it does limit the length of time such steels may be held at heat.

The above terms "cyanide martensite" and "cyanide austenite" are suggested by the author for these characteristic structures which are developed on cyanide treatment. Although their appearances resemble the corresponding iron-carbon structures, they possess their own characteristic chemical and physical properties.

Scumming Baths

Some metallurgists prefer to use scumming cyanide baths for reheating, because the black scum decreases the rate at which cyanide decomposes and enables the operator to use higher cyanide concentrations. The bath is then made up and replenished with high test cyanide and normally contains approximately 50% cyanide. When clean cyanide baths are used they are usually made up with 45% mixture and replenished with either 75% or 96% cyanide. There is no advantage in maintaining the clean cyanide bath above 35% cyanide. However, it should not be allowed to deteriorate much below 25% because then the activity is so decreased as to affect the composition of the case produced in a given time.

The table shows clearly that the scumming bath in 30 min. will increase the carbon materially on S.A.E. 5150 and 6150 steels, while in the same amount of time a clear bath has little or no effect on this element. However, nitrogen absorption seems to be independent of the sodium cyanide concentration in the bath.

A Paper Read at Melting Session Boston, Sept., 1931

Melting Tool Steel in basic electric furnace

By J. P. Gill and M. R. Trembour
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ABOUT 1910 the electric furnace began to displace the crucible furnace for the manufacture of tool and other high-alloy steels, and at present only a very small percentage of our total production is still made in the latter. While the economic advantages of the electric melting process were recognized early, it is indicative of the ultra-conservative spirit of our tool steel industry that the transition from the old to the new method took place very slowly.

The old crucible furnace was strictly a melting furnace in which the refining of the charge was confined to the removal of a single element, namely oxygen. For the elimination of this obnoxious element, the crucible process, when properly conducted, was admirably suited. Even today we still have mills in which this very adaptable furnace is used in the same restricted way as the old-time crucible, namely, for straight melting of high-grade material.

Of the many principles originally employed to melt steel electrically, it appears that only the system employed first by Heroult has stood the test of time. The steel, in a closed furnace, forms the common conductor for the current led in by electrodes through the roof.

The hearth of the electric furnace must be a basic material, such as magnesite or burned dolomite, to withstand the lime slags used in the basic process. Walls and roof need not be basic, but must be capable of withstanding extremely high temperatures — silica brick is used almost exclusively.

The hearth may be rammed in by layers, using a binder such as sodium silicate, molasses, or tar, then burned in. Otherwise, the bottom material, often mixed with a suitable flux such as basic open-hearth slag, is shoveled into the hot furnace and burned in layer by layer. This is done by the heat of electric arcs formed between the furnace electrodes and other electrodes placed temporarily across the hearth.

Selected steel scrap comprises the bulk of the charge. It is of such a composition that upon melting down the bath will contain a smaller percentage of the various alloying elements than is required in the final steel.

Of equal importance to composition is the physical condition of the charge. If it is too loose and bulky, the electrodes will cut their way through to the bottom before sufficient molten metal accumulates, and the bottom will melt. If the charge is too dense and melts slowly, the roof and sidewalls will suffer.

If large amounts of slag-forming material or of scale or ore are charged with the scrap, the electrical conductivity of the charge may be too low for the voltage of the circuit and an electrode may freeze. If heavy scrap is charged on top, it may break an electrode when falling. Scrap requiring a long time to melt may chill on the bottom or pieces of it may even float for an indefinite length of time in the bath. Loose and heavy scrap should therefore be distributed in such a way that the electrodes cut their way

at least two-thirds through the charge before becoming stationary and starting to back up. This protects the bottom of the hearth, melts metal at the lowest point, and protects walls and roof.

All non-oxidizable alloys, such as tungsten, molybdenum, nickel, and copper should be charged directly with the scrap, distributing it carefully in the upper central part near the electrodes. Ores or oxides (charged with the scrap for direct reduction with whatever reducing agent be used) are put throughout the central part of the charge, making sure that there is sufficient furnace voltage to overcome the increased resistance. Molybdenum oxides may be charged without admixture of a deoxidizer, and in a heat that is to be melted under oxidizing conditions. Chromium oxides may be reduced after the heat is melted.

Some Oxides Slightly Volatile

Tungsten and vanadium oxides are somewhat volatile; heats containing them should therefore be melted under reducing conditions and provision made in advance for the addition of deoxidizers. For instance, if ferrosilicon is used for deoxidation, about three pounds of lime should be added for each pound of silicon in the charge.

Melting is usually done at as high a voltage as possible, to melt quickly, increase furnace economy, and decrease losses. To accomplish this most furnaces are equipped with variable voltage transformers. For the first 15 or 20 min., until a pool of metal is formed, the electrodes "search" (raise and lower as they melt through the scrap), and the current fluctuates widely and rapidly.

The melter pushes the unmelted scrap toward the center of the furnace, cleaning off the banks, and gradually working all loose scrap into the bath. First slag additions are then made, consisting usually of burned lime with a little fluorspar or sand as flux. These combine with the oxides formed during melting into a highly oxidized basic slag (containing a large excess of calcium oxide).

Refining operations in the electric furnace are based largely upon reactions between steel and slag, which are confined to the contact surfaces. Reactions also take place within the steel itself (and within the slag itself) between certain original constituents and others that may have been added for the purpose. These reactions aim to accomplish three distinctly different purposes, and, since they would conflict with each other in several ways, must be carried out separately and in a fixed sequence.

First comes the removal of oxidizable elements (principally carbon and phosphorus, but sometimes also manganese and chromium) by oxidation. This process is carried out by adding an oxidizing agent to the slag, usually iron oxide. If it is intended to remove the carbon, the scale or iron ore is added after the temperature has been raised as much as possible; at low temperatures it is possible to oxidize the other elements without burning out all the carbon.

If phosphorus is to be removed (or manganese or chromium), it is necessary to pull the resulting black slag, since these elements are held only in a highly oxidized slag. The furnace is tilted slightly and the slag is raked off and out the door.

If the scrap is of such a character that phosphorus does not need to be removed, the slag is at once "turned over" — that is, whitened or deoxidized by adding crushed coke or ferrosilicon. This reduces the alloying elements that have accumulated in the slag, and returns them to the steel. If the phosphorus slag has been removed a new slag of lime and fluorspar is made and worked with coke or ferrosilicon as noted above.

This working of the slag is the second stage in refining. The oxides to be reduced from the slag may have been formed unintentionally during the melting of the steel, they may have been added for the purpose of direct reduction, or they may be continuously formed from loosened particles of hearth and patch material.

This deoxidation of the slag may be carried out by finely divided carbonaceous material, or by calcium carbide which is the quickest acting and therefore probably the cheapest. It may be mixed to advantage with some fine ferrosilicon. A change of the slag from black, brown, or green to a pure white indicates the complete reduction of all reducible oxides, whereupon from 1% to 2% (with reference to slag weight) of carbide may be added and the

Photograph by Eugene Hutchinson for Colorado Fuel & Iron Co.

steel left to itself for a short time, preferably at a low temperature to reduce the solubility of certain oxides contained in the steel, and give them a chance to eliminate themselves.

The last step in refining is deoxidation of the steel. This consists of converting soluble oxides into insoluble ones, and their separation from the metal by flotation. This separation is greatly facilitated if, instead of forming a highly infusible oxide such as SiO_2, we attempt to form at the same time several such oxides, which, through combination with each other, become fusible slag particles which coalesce into larger globules. For this reason the final deoxidation is usually carried out by so-called double deoxidizers, such as calcium silicide.

Desulphurization of the bath also takes place at this time, the sulphur combined with manganese rising to the surface of the bath, where it reacts with lime to form calcium sulphide which is absorbed and held by the white basic slag.

A deoxidizing agent should be present in the slag during the final period. There is only one such agent that can exist in the slag, namely, calcium carbide. This carbide has practically no deoxidizing effect upon the steel; its role is to reduce oxides of iron, chromium, manganese, tungsten, or vanadium which have risen into the slag.

It is therefore of no advantage to hold the steel for a great length of time under a strongly carbidic slag. On the contrary the presence of much carbide conceals faulty conditions in the furnace practice which are apt to cause the very troubles carbide is intended to remedy. Every melter is familiar with the fact that a slag containing no carbide is apt to "change" or to "turn." This change is due to oxides which come up from the hearth. Bottom or patching material contains as much as 5% iron oxide, and if it comes loose in fine or large particles and passes through the metal, it will react with carbon, silicon, manganese, or chromium, thus undoing the work already accomplished.

It is therefore advisable to use the carbide sparingly, so that such faulty conditions, if they exist or develop, can be detected at once and can be remedied. Stirring during the last stages tends to loosen more hearth material and also stir back into the metal oxides and sulphides which otherwise would remain in the slag. It is quite analogous to stirring up a precipitate that is about to settle.

Beginning at the time the bath is first melted clean, occasional spoon tests are poured and sent to the chemical laboratory for quick determination. Additions, necessary to bring the final composition of the heat within specified limits, are usually made during the final refining period in the form of ferro-alloys, the exact compositions of which are known. Carbon may be added either by turning off the power and submerging the electrodes, or by adding a calculated amount of wash metal or carbon briquettes.

Having brought the bath to the required chemical composition, a number of spoon tests are taken to determine its temperature and deoxidation. On straight carbon and a few alloy steels, it is possible to determine the proper temperature by the so-called film test, which consists of taking a sample in a well-slagged spoon and noting the time required for a film to freeze over the surface of the steel. Temperature is otherwise determined by pouring the steel from a well-slagged spoon in a uniform stream into a little test mold; no frozen metal should remain in the spoon and the cast should have smooth sides without wrinkles. The top surface also gives some indications as to the presence or absence of soluble oxides; it should be smooth and free from eruptions and slightly depressed in the center. Final deoxidation is accomplished in the furnace with ferrosilicon and ferromanganese.

The heat of steel, now of proper composition and temperature and properly deoxidized or killed, is ready to tap into the ladle. This operation, as well as the final pouring, may have as great an effect upon the quality of the finished steel as has the melting, since the metal is now exposed to atmospheric oxygen.

Opinions vary as to the best method of tapping. Some prefer to hold the slag back, which necessitates tapping through a runner brick or skimmer spout. A runner or nozzle results in a relatively small stream, and the surface of the steel in the ladle is exposed to oxidation up to the last moment. Others prefer to tap steel and slag together quickly. This practice lessens oxidation, but may entrap finely disseminated slag particles. Which of the two evils is the lesser depends probably upon the type of steel and the purpose for which it is intended, and also upon the condition of the slag. Tapping temperatures are often taken with the optical pyrometer. Usually no deoxidizers are added to the ladle, although occasionally small additions of aluminum may be made to counteract the tendency toward oxidation during the tap.

After holding in the ladle a sufficient time to float entrapped slag, the metal is teemed into molds. Oxidation by atmospheric oxygen again occurs. It is obvious that all splashing should be prevented. Silicon present in the steel will prevent the formation of soluble oxides which might cause porous ingots, but, on the other hand, the formation of insoluble silicates and heavy oxides, especially those of chromium, can never be entirely avoided. However, if the metal is poured at the proper temperature so that it will run smoothly in a compact round stream striking steadily in one spot near the center of the mold, this oxidation can be kept at a minimum. A certain amount of protection is given by mold dressings, such as tar or rosin soot, which expel the air by forming more or less inactive gases and which also prevent oxidized splashes from sticking to the walls.

Sound ingots, free from shrinkage cavities, are insured by proper mold design, heavier walls near the bottom, and a chamber gradually widening toward the top, and by a so-called "hot top" (a brick placed on top of the mold to act as a reservoir, from which the the ingot is continuously fed until completely solidified).

By J. F. Schrumn
Process Engineering and
Equipment Corp.
Attleboro, Mass.

Bright Annealing

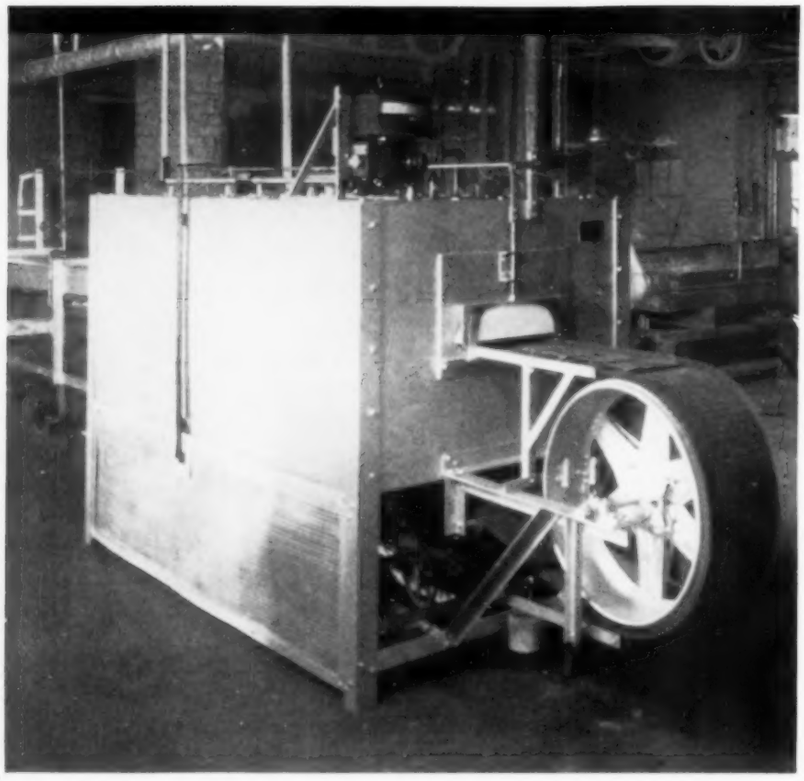
and other operations in controlled atmospheres

ANNEALING is an operation which nobody does merely because he likes to do it. It is a necessary evil in the production of most fine metal products, particularly wire, thin sheet or strip, or things made from them. In articles having a large surface in comparison with mass, the condition of that surface becomes of prime importance. Losses from heat scale and oxidation during fabrication must be minimized — hence as much work as possible is done cold. Unfortunately, even the most workable of the alloys harden under cold work, and many articles require so much rolling, drawing, hammering or pressing before they are finished that it is necessary to re-soften them by annealing operations.

Obviously, surface oxidation should be prevented during this necessary step, else the part may be ruined by scale pits, or lose too much metal in oxide, or become too expensive from the added operations like pickling and bufling necessary to remove the scale and get the surface back into good condition. Hence the desirability of "bright" annealing.

Theoretically, bright annealing is a simple operation. All that is necessary is to heat the metal in an atmosphere which has no oxygen in it, or any other gases which would discolor the surface at the temperatures necessary for annealing. Practically, it is not so simple as it appears theoretically to discover an inexpensive manner of creating such an artificial atmosphere, nor to build a furnace which will hold this artificial atmosphere inside of it and the natural atmosphere out, particularly during a continuous procession of chargings and discharging operations.

Batch furnaces for annealing in controlled atmospheres have been in operation in some branches of industry for many years. One of the earliest solutions of the problem of heating without forming scale was effected by the cold rolled strip industry. A load of coiled ribbons of steel is heaped over with cast iron chips, and the whole is covered by an iron casting, like an



Conveyor Furnace for Bright Annealing Stampings Which Replaced Two Fuel-Fired Furnaces and Reduced Handlings From 36 to 3

inverted bath tub. As the temperature is raised, oxygen inside the container is consumed by the iron chips rather than the steel strip.

Such an operation has the advantage of simplicity, but the disadvantage of having to heat several pounds of inert equipment for every pound of work. Also it is discontinuous, and consequently uneconomical. Again, the time required for each heating and cooling increases the length of the process two or three days at the least.

Some of these disadvantages are avoided by methods used in the electrical industry for annealing transformer laminations (punched from sheets of silicon steel) in an atmosphere of hydrogen. This process not only preserves the surface during a long time at heat, but also improves the magnetic characteristics of the metal — possibly by the removal of last traces of oxygen in it. Ingenious methods of introducing a pile of sheets into the furnace, of generating the correct gases, and of controlling the annealing cycle have enhanced the success of this operation.

Bright annealing entered the non-ferrous industry three or four years ago by a combination of circumstances which enabled the first trials to be made with furnaces of quite small size and on articles of considerable intrinsic value. The first factor — small furnace size — was an advantage, because if the furnace proposed for the work was not entirely successful, it could be taken apart and modified without much expense. Furnace development, therefore, was on inexpensive units. Secondly, the cost of an annealing operation on high priced articles is such a minor part of the entire production cost, that a slight increase in the expense of heat treatment had a good chance of being recovered in collateral advantages, or savings in some other associated operation. Hence the bright annealing idea could be considered on some other basis than low cost, and if annealing in a controlled atmosphere had to wait until it could be done cheaper than annealing in a hit-or-miss furnace atmosphere, bright annealing would still be a laboratory curiosity.

For such reasons as outlined, my first design in this field was installed by Summers Brass Company, of Waterbury, to anneal thin nickel strip in a hydrogen atmosphere. Nickel was to be used in radio tubes, and had to be clean and oxide-free. Pickling was to be avoided because of the deleterious effect of acid on the surface conditions best suited for the intended electrical characteristics. Annealing in a coil was impracticable, because recrystallization during anneal produced grains much larger than the thickness of the strip (0.002 to 0.004 in.) and the growing grains in one layer would absorb metal from another layer, thus effectually "freezing" the coil together.

In this first furnace a vertical chamber was

used. A bottom opening turned out to be a very good idea for any container of light hydrogen gas, but this part of the design was adopted for the work, rather than the atmosphere. Since the bright nickel strip had to be delivered with a mirror-like surface it could not be dragged across a furnace bottom and get scratched. Furthermore, if the hot strip were put under enough tension so it hung from end supports, free from the hearth, it would emerge with wavy edges (since the distribution of stress in thin cold rolled strip is far from uniform).

Such disadvantages were avoided by leading the strip into a vertical heating chamber, over a roller at the top, down a cooling chamber alongside, and out to a coiling reel. No contact with the furnace was made, and the only load on the strip was the weight of a length equal to the height of the furnace (approximately six feet), and a minor brake tension. Results were entirely satisfactory.

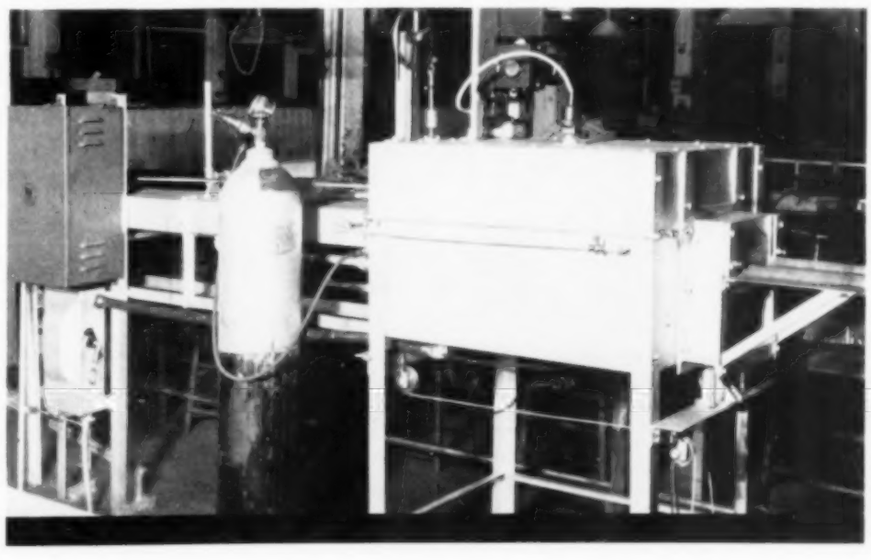
Pursuing the idea of working with expensive articles, the next applications were in the jewelry trade. Vanity cases and costume jewelry of considerable merit become relatively inexpensive when made in quantity by labor saving machinery. Machine fabrication requires more annealing, however, and annealing of a sort which does not harm the surface. Bright annealing of silver strip during cold rolling has also been very successful, for the anneal is uniform and produces a surface which can be buffed readily to a required polish — there being no scale nicks nor etchings nor pits from pickling solutions.

A short experience with gold, silver and nickel alloys in the jewelry trade indicated that the principles and equipment for bright annealing could also be used for soldering various small units into marketable articles.

As is well known, an article must be clean before solder will alloy with the surface. In soldering by hand, a surface would be filed, sand papered or buffed, and then soldering "flux" would be used to dissolve and remove the remaining traces of oxide or dirt. But in bright annealing no flux is necessary, as the oxides on a surface are reduced by the chemical action of the artificial atmosphere which leaves metal in most excellent condition to unite superficially with the solder — the latter, in fact, is drawn into and between tightly fitting surfaces by capillary action of amazing penetration.

Thus it occurred that successful furnaces have been installed for soldering knife handles or silver handles for other flat ware. These are thin stampings of sterling silver (or nickel silver for cheaper ware) made in pairs so two of them form a hollow handle. When soldered together they are ready to be fixed to the tang of the knife blade. Such soldering by machine has replaced the hand soldering operation.

To mechanize this operation we built what is probably the first conveyor furnace using atmospheric control. As shown in the photograph on page 78 the first or heating portion of the



Furnace With Controlled Atmosphere for Bright Annealing Stampings of Gold, Silver, and Brass Used by Jewelry Manufacturers. Doors at both ends of heated chamber depress and top portion forms part of smooth trough along which run work-containing trays

device consists of a well-insulated electric furnace, carefully designed and controlled by automatic pyrometric devices for a correct temperature gradient. Work is placed on the conveyor — a woven wire belt of heat-resistant alloy — and continuously moved through. (Conveyor is geared to motor through a variable speed device, so the time cycle is also under control.) After passing through the heated chamber the work enters a relatively long, water-jacketed cooling chamber and emerges at the far end at room temperature.

One operator loads the conveyor and unloads at the other end, watches the temperature and speed controls. Production varies from 60 to 125 dozen handles per hour, depending upon the size of the unit. This results in a great saving in labor costs. The handles are also oxide-free and require a minimum of buffing or other finishing. Lastly a cheaper silver solder can be used, having a higher melting point than can be used with hand soldering without danger of melting or deforming the stampings, yet one which works perfectly in the furnace where the heat is exactly controlled. It is apparent that the operation is one which is much cheaper in over-all cost, and consequently has been of advantage to those manufacturers who are meeting severe competition in this industry.

Similar furnaces are being used for soldering chain, for making cuff links, for annealing first grade stampings for badges, emblems and escutcheon plates in many different metals, and for assembling cigarette lighter shells, cigarette cases and vanity case parts.

Soldering is only one phase of bright annealing. Annealing, as such, of drawn or stamped metal parts in a conveyor type of furnace, has resulted in economies as great as has machine soldering. It has eliminated the operations of pickling, cleaning and drying, and produces softened articles unmarked by scale pits or etched by acid solutions. Bright annealing applications have varied from the normalizing and annealing of strip steel and steel tubing and parts made therefrom to the bright annealing of cartridge shells or gold plated optical and jewelry findings. In each application, quality or economy has been the decisive factor.

One of the most recent and interesting applications has been for the manufacture of "bimetals." These are used in the jewelry and instrument trades, such as gold on german silver for watch cases, white gold on silver, and green gold on brass for jewelry, and invar on nickel or other metals for thermostatic control purposes. Ordinarily plates or bars of the two would be soldered together in such a way that the combination billet can be rolled down into sheet wherein the precious metal represents a very thin veneer over the similarly-colored metallic backing.

The conventional method of making the composite billets is to clean the abutting plane surfaces carefully, flux them with some borax, place a thin sheet of silver *(Cont. on p. 100)*

Sterling Silver Knife Handle and Nickel Silver Cigarette Lighter Shell. Each is stamped in half, joined into a hollow unit by silver solder. The operation is automatic in an atmosphere of hydrogen

Pure Aluminum Versus Alloyed Aluminum for Transmission Lines

NEW YORK — We feel we must raise an objection to a statement in the foreign letter from Dr. Federico Giolitti in August METAL PROGRESS to the effect that in the case of "Mixed cables of pure aluminum and steel wire . . . . very soon the serious disadvantages of this type of cable were discovered, especially in the corrosion phenomena taking place in the bi-metallic system, and in the mechanical difficulties due to the differences of the modulus of elasticity of aluminum and of the steel core."

We wish to point out that steel cored aluminum cables if properly manufactured, using clean aluminum wire of 99.5% purity and properly galvanized steel wire, will resist interior corrosion indefinitely. All that happens with these is a slight oxidation of the exterior exposed surfaces of aluminum wire which is of negligible effect on the life and performance of these conductors. We have examined samples of steel-cored aluminum stranded conductors that have been in lines exposed to the atmosphere for several years and have found the interior surfaces of aluminum and the galvanized steel to be similar in appearance to new wire. Regarding the suggested mechanical difficulties due to differences of the modulus of elasticity of aluminum and steel, we would say that no such difficulties exist in practice.

Without questioning in any way the possibilities of the comparatively recent aluminum alloy conductors for overhead lines, we would point out that there is over 20 years' satisfactory experience with steel-cored aluminum conductors and that the present world output of these conductors is considerably larger than that of aluminum alloy.

For aluminum overhead conductors steel-cored aluminum is exclusively used in America and England. For the British "Grid" or super-power system, several thousand tons of steel cored aluminum conductors have been erected within the past two years, and have performed entirely satisfactorily.

BRITISH ALUMINIUM CO., LTD.
By A. J. Field.

* * * * *

TURIN, Italy — In respect to the rapid development of the use of aluminum alloy cables for the new Italian electric overhead transmission lines: The alloy known under the commercial name "aldrei" is practically the only one used in Italy for this purpose. The entire cable may be and is usually made entirely of the aluminum alloy — no core of steel being inserted, as is necessary for pure aluminum wire.

A group of lines having a total length of about 5,000 km. — mostly located in high mountains or on the sea-coast — seems quite sufficient to draw practical conclusions concerning the behavior of the new material.

Physical properties of aldrei alloy, drawn and heat treated, have been studied with great care from the beginning, and special attention was paid to the design of transmission line clamps and to the materials used for them. A uniform type of non-vibrating clamp has been generally adopted, made of the aluminum alloy called "anticorodal," which has already been mentioned in a previous letter. These clamps have completely eliminated all corrosion at the grips, and have proved especially efficient in avoiding breakage due to the resonance phenomena produced by winds of low intensity and long duration.

In fact, in the Italian lines so constructed in the past three years no breakages have taken place, while such accidents have been reported to be rather frequent in the German and American high tension lines. This fact is especially notable when it is considered that many of the Italian lines have very long spans between supporting towers.

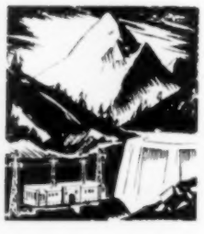
For example, I may quote the 220,000-volt

mountain line from Cislago to Fiume Oglio, constructed with aldrei cables of 61 wires of 2.82 mm. diameter each, and the 135,000-volt Valsugana line of cables having 37 wires of 2.63 mm. diameter each. These lines have frequent spans of more than 600 meters, many of them being more than 700 meters long. In these and many other similar lines in the high mountains, no breakages have occurred, notwithstanding an exceptionally heavy snowfall and strong winds during February and March, 1930.

In a few unusually long spans of small cables, mixed cables (aldrei with steel wire core) have been used with excellent results. In the opinion of the constructing engineers, these last cables are superior to the composite cables of pure aluminum and steel wire, both from the point of view of resistance to corrosion, and of mechanical strength. There is a smaller difference in the physical properties — especially the elastic limit and the modulus of elasticity — between aldrei and steel than between pure aluminum and steel.

If the development of these new high-tension lines of aldrei alloy has not yet been very great (a total length of only about 5,000 km.) this is due to two causes:

The first is of general character, namely, the world-wide economic depression which has greatly hindered the construction of new high-tension lines. The second cause has a more special character, because the year 1928, which witnessed the construction of the first experimental line of aldrei cable, also corresponded to the date when the great group of high-tension lines had been completed connecting the different parts of the Italian distribution system. New lines recently constructed are only secondary parts of that large system. Nevertheless, many of these shorter links are now under construction, and aldrei cables are being used almost exclusively.



Certain metallurgical features concerning the manufacture of the wire may be described later. Its heat treatment is planned to segregate as completely as possible the materials in solid solution, in order to obtain the highest possible electric conductivity, and also to produce an optimum tensile strength. A high degree of uniformity has been achieved in the rolling, drawing and heat treatment.

FEDERICO GIOLITTI

Two-Cycle Anneal for Malleable Iron

SENDAI, Japan—A malleable iron industry has been developed in Japan quite recently as compared to Europe and America. In 1910, Y. Aikawa, president of Tobata Foundry Co., established the first malleable iron foundry in our country; now his company has two other foundries, one in Osaka and the other in Tokio. Besides these, 15 minor foundries are now making malleable castings.

Production of Tobata plant, the oldest and biggest in our country, amounts to about 5,000 tons annually of all kinds of malleable iron castings for railroad equipment, trucks, automobiles, electrical machinery, and articles used in high tension transmission lines. The Kizugawa plant in Osaka, established in 1921, has been well arranged with modern labor-saving equipment, and all kinds of pipe fittings are manufactured here. Tobata's Tokio plant is the newest one, established in 1929, and it makes the same varieties of castings as does the Tobata foundry. Annual production of these three amounts to 10,000 tons, which is about 75% of the total demand in our country.

Since 1920, the Tobata plant has had a well-equipped routine and research laboratory with Dr. T. Kikuta as the director. His investigations on malleable cast iron, steel castings, and other foundry materials have been continuous. A brief account of developments in the last several years will be given.

When the Tobata plant was built the manufacturing process and the equipment were about the same as found in American practice. Air furnaces were used to melt; annealing furnaces were heated with heavy oil or coal gas and afterwards replaced by pulverized coal. It was believed, as was general at that time, that packing material was an indispensable substance to anneal white cast iron; Tobata used such packing materials until 1925 and therefore required 7 to 10 days and even more to make black heart malleable cast iron.

The first improvement in conventional practice, installed as the result of research, was an attempt to use an electric furnace for melting iron. After several trials, a duplex method — electric furnace and cupola — was found to be most convenient; hence the air furnaces were replaced. At the present time materials for white iron castings are melted by this method, using four electric furnaces and one cupola.

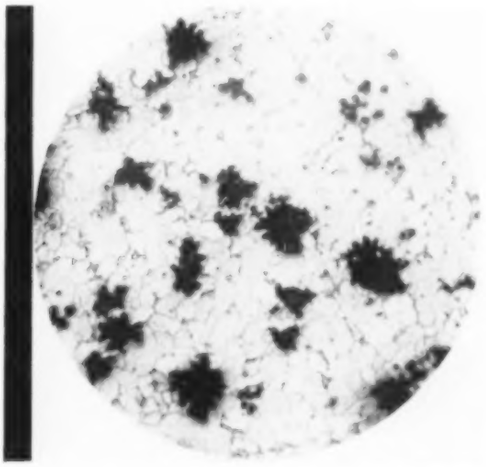
In 1925, Dr. T. Kikuta completed his investigation of a new method of annealing for making the black heart malleable cast iron, which he has described in *Science Reports*, Tohoku Imperial University, Vol. 15, No. 2, p. 115. Packing materials have been completely abolished by this new process. Packing materials caused an unnecessary consumption of heat and an unduly long annealing period.

The principal object of annealing a white cast iron to make a black heart malleable iron is to decompose completely the cementite contained in it into soft graphite and ferrite. It is an established fact that free cementite can easily be decomposed into its components by annealing at high temperatures, but on the other hand, that portion of the cementite which is dissolved in austenite hardly decomposes at all. Hence, in order to cause the complete decomposition of cementite it is necessary to anneal in two stages, first at 900° C. (1,650° F.) and then at a temperature below the Ar_1 point. By the first annealing (at 900° C. for about 10 hr.) the proeutectoid cementite above A_{cm} line is completely decomposed. By the second annealing (at a temperature a little below Ar_1 for 25 hr.) the pearlitic cementite as well as the remaining proeutectoid cementite below A_{cm} line are both decomposed.

White cast iron thus treated is completely graphitized and shows the normal structure of black heart malleable cast iron, that is, a structure in which temper carbon surrounded by ferrite appears scattered over the ferrite ground. The total time of annealing for two stages amounts to only 35 hr., and no packing materials are used.

Based on these experiments, Tobata and its branch foundries are now adopting electric power as the source of annealing heat, by which several advantages, such as uniform heating of the cast articles and easy regulation of temperature, may be obtained. The new method of two-stage annealing is also practiced.

Several years ago, when pulverized coal was used as fuel, the annealing of white cast iron required 7 to 10 days; but at present the annealing period has been reduced to three to four days — even to two days, since a new type of electric annealing furnace has been constructed. Another valuable result has been found: Embrittlement of malleable cast iron after galvanizing has been completely avoided.



Microstructure at Center of Black Heart Malleable Iron Made by Double Annealing Without Packing Material and in an Electric Furnace

In this way the Tobata Foundry Co. is now making black heart malleable iron castings at a low cost which have a good uniform quality. For example, test pieces from 10 heats gave the following results on 0.56-in. test pieces: Ultimate tensile strength, 55,000 to 61,500 lb. per sq.in. (average 58,000); elongation in 2 in., 16 to 21.5% (average 18.0).

The product is of such quality and price that a considerable export trade in pipe fittings and link chains has been developed in China, India and South Sea Islands. Some shipments have been made to Europe and the United States of America.

TARIO KIKUTA

Practical Limitations Often Prevent Perfect Hardening of Steel

PARIS, France — In practice the problem of hardening a given piece of steel is much more complicated than would be supposed by reading chapters on this subject in the standard treatises or textbooks. In fact, the object of hardening steel is merely to obtain a definite strength or durability and at the same time to avoid as far as possible those phenomena which increase its brittleness (such as superheating). The matter is related to definite objects to be attained. Furthermore, there are certain practical conditions imposed upon the operation by the available equipment used by the steel industry. Lastly, the problem is specific, since it is not an ideal steel which is to be treated but a definite piece made out of a commercial steel.

In a word, the conditions of hardening are defined by the characteristic curve of the steel (a subject which was discussed by the writer and P. Chevenard in 1921 before the British Iron and Steel Institute) and three other conditions:

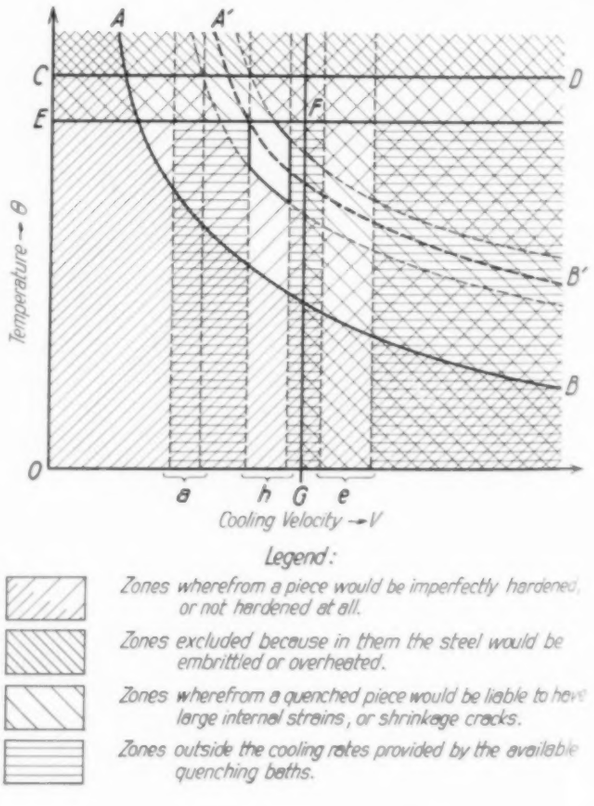
First, there are certain economic and industrial limitations which affect the heating operations and which restrict the quenching to definite mediums, generally three baths — water, oil, or air.

Second, due regard must be had for the proper depth of penetration, which varies with each piece and its intended destination.

Third, one should avoid altogether, or at the very least, reduce to the minimum the number of rejects due to change in dimension or quenching cracks. Equally important is it to avoid placing into service pieces which possess a high amount of internal strain.

The simultaneous interaction of these various requirements comprises the real and only difficulty met in the hardening process. It is thought that the diagram presented herewith will therefore be of value in illustrating these various industrial influences as a function of the two principal variables, namely, the cooling speed, which is plotted in the horizontal direction, and the hardening temperature, which is

Diagram Showing How Certain Workshop Limitations Restrict the Speed and Temperature of Quenching for Hardening



plotted vertically. This diagram and method of representation assumes that the hardening of a piece of steel may be defined by fixing the heating temperature and the cooling velocity. In other words, it would be located by the intersection of two coordinates, Θ and V. It is easily seen that in such a figure every limiting condition narrows the acceptable range for proper hardening.

In the first place, if the steel is to be hardened at all, the intersection of the coordinates Θ and V (that is to say, the quenching temperature and quenching velocity) must necessarily be above the curve AB, which may be called the critical hardening curve, being a function of the composition of the steel and of its past history or condition just before hardening.

Second, assuming that the maximum of martensite is to be obtained in the piece (since this corresponds most frequently to the best mechanical properties), the intersection of coordinates must be in the vicinity of the curve $A'B'$, which may be called the curve of maximum hardening and is again a function of the steel and of its initial state.

Third, the penetration of hardening is limited by the quenching baths which exist in the various workshops, so that the practical quenching rate is located within a certain number of vertical strips e, h, or a, the width and the position of which depend upon the size and configuration of the piece, on the nature of the quenching bath, its agitation and its temperature. The position of these vertical strips can therefore be altered to a rather large degree. Likewise, the influence of drastic hardening may be lessened by tempering.

Fourth, to avoid overheating the steel, the quenching temperature must necessarily be under the line CD, which is a function of the composition of the steel, its initial state, and the time at heat.

Fifth, in order to minimize the consequences of internal strains, such as warp, change in dimension, and quenching cracks, the intersection of coordinates must fall below the temperature EF and be less than the speed FG. This temperature and speed depend on one another, and again are a function of the form and dimensions of the piece and its expected utility.

It can be appreciated that the field wherein a perfect solution of the quenching problem can be found is quite circumscribed — when, indeed, it ever exists.

It is admitted that this graphical representation of the problem is quite simplified and is qualitative and perhaps imperfect, but it does seem to have one advantage; namely, it shows clearly the interference and superposition of several factors which enter the general problem in its day-by-day applications.

It is obvious that in many instances a perfect solution of the problem is impossible. We may then have recourse to sundry proceedings, such as to preliminary heat treatments which refine the structure and make it more uniform, to a considerable modification of the cooling rates, as by interrupted or limited hardening, and to the careful selection of steel to eliminate minor physical defects.

ALBERT PORTEVIN

Sponge Iron Low in Impurities By Ekelund's Process

STOCKHOLM, Sweden — In several previous letters from Sweden the problem of producing iron sponge has been mentioned. The method invented by Sven Ekelund has recently been very thoroughly tested on a semi-industrial scale, and the promising results, which have just been made public, are of considerable interest.

According to Ekelund's method the ore is reduced by gas generated in a slagging producer from a mixture of coke and coal. In order to obtain a gas with a constant composition, high in CO and H_2, free from CO_2 and with a low content of hydrocarbons, part of the gas is recirculated.

The gas passes through a chamber above

the producer containing fuel, which latter is in this way subjected to dry distillation. The gaseous products of this distillation are conducted through the producer, where they are decomposed.

Preheated air is used in the producer, and the gas, which is taken out at a certain level below the upper surface of the fuel, has a temperature of 1,000 to 1,050° C. (1,900° F.).

At the tests mentioned the fuel consisted of a mixture of 42% coke, 51% coal and 7% charcoal. The average composition of the gas was found to be 33.6% CO, 9.8% H_2 and 0.7% CH_4. The gas was free from CO_2. Part of the sulphur is removed in the producer, and the gas is further purified by means of a lime filter.

The continuous, horizontal furnace in which the reduction takes place has a circular cross section, the ore is conveyed through it on moving plates of heat-resisting iron alloy. As the charge settles somewhat when passing through the furnace, the roof is lowered towards the outer end, and the charge thus fills the section through the entire length.

When entering the furnace, the gas has a temperature of about 950 to 1,000° C. (1,800° F.). The ore is preheated by means of burning waste gas from the reduction furnace. Throughout the entire length of the furnace the temperature is kept practically constant. As a valuable by-product fairly large quantities of combustible gas are obtained.

Experiments were made with ore from Stripa containing 46% Fe, and also with sinter containing about 67% Fe. The crude sponge obtained from the Stripa ore was concentrated magnetically and was then found to contain 92.8% Fe and 0.008% S. From the sinter a sponge was obtained with 93.7% Fe. Of the total iron content, 87 to 92% was found to be reduced to the metallic state. The nitrogen content of the sponge was found to be only 0.002%.

At these experiments on a semi-industrial scale the producer was somewhat large in comparison to the furnace, and the fuel consumption was therefore as high as 1.25 ton per ton of metallic iron in the crude sponge. On a full industrial scale, however, it is counted upon that the fuel consumption can be lowered to about ton for ton. When this is achieved, the cost of production of briquettes pressed from the sponge would be 15 to 20% lower than the cost of high class pig iron.

EINAR ÖHMAN

Reliability of Steel Boiler Shells in Marine Service

BIRKENHEAD, England — One of the most interesting metallurgical documents issued during the present year in England is the memorandum of the Engineer in Chief of the Manchester Steam Users' Association for the prevention of steam boiler explosions and for the attainment of economy in the application of steam. The association in question is really an insurance company and the writer of the report has unique opportunities of investigating all boiler difficulties.

He deals particularly with the behaviour of steel at high temperatures. This is a matter of extreme importance in that there has been since the War an insistent demand for greater economy in the production of power, and at the present time it is being accentuated by world-wide economic depression. The boiler maker, therefore, has been driven to construct boilers capable of withstanding pressures which, until a few years ago, would have been regarded as fantastic. In addition to this, temperatures of superheated steam have reached limits which are definitely set by the possibilities of metallurgical achievement to date.

The Engineer in Chief goes very fully into methods of testing boiler material, which for want of anything better, is steel. It seems very

unlikely that for some time, at least, any substitute will be found for this material. He discusses the available methods of testing, paying particular attention to "creep" tests and the behaviour of the material at temperatures approaching the working conditions. He also deals fully with cases of failure of boiler material which have come under his notice during the year and considers them metallurgically as well as mechanically.

Your correspondent is chiefly concerned with the mercantile marine and it should be recorded that the number of failures of boilers on steamships is extraordinarily low. In fact, he has only this year observed the first fracture of the shell plate of a Scotch boiler in his experience. Personal experience is therefore somewhat meager, but a summary of the facts which are generally accepted may be of value in order to appraise the modern trend in strong steels.

The failure of boiler plates can be roughly classed in four headings: Defective material, bad workmanship, caustic embrittlement, and design. Engineers have had so much experience that it is very unlikely the design is at fault. Caustic embrittlement as a cause of metallurgical breakdown is a theory which is held in much favor in many portions of the United States, but in my opinion, many of the instances quoted are not proven. The normal practice in this country is to take full mechanical tests of the boiler plate and also to examine it under the microscope, with a view to determining the structure. It is also the standard practice to normalize shell plates for boilers. Consequently the probability of bad material is excluded.

This, by subtraction, leaves the question of workmanship as the most likely cause of failure in boiler plate. Something could probably still be done to raise the standard of riveting, though again the experience of the marine engineer has been a very happy one.

As I have already remarked, the number of failures of marine boilers is so low that one has very little experience with them. I hope shortly to be able to examine a set of boilers which have given thirty years' efficient performance, and then to be in the position to pass an opinion on the question of riveting, caustic embrittlement, workmanship and material. There are very few records available on this subject. A good boiler is seldom examined with minute care (other than routine inspections).

While on the question of the increase in the duty which steel is called upon to bear, it would be well to draw attention to the manufacturer's side of the question. It is perfectly true that there are many of the alloy steels which have extraordinarily good mechanical properties and which, on testing at least, are well suited to bear the abnormal stresses which modern engineering practice imposes. At the same time, they are costly, the demand for them is small and the amount of production is limited. Consequently, the experience of the steelmaker is equally limited, and the possibilities of producing the perfect article are limited. In the writer's opinion, it will be a long time before anything is produced in quantity to beat a good piece of ordinary mild steel. The writer well remembers his difficulties when double reduction gears were first introduced and nickel-chromium steel pinions were considered *the* desirable product. On one occasion he had to scrap nineteen first reduction pinions before he got a sound one. Long experience in the steel works, machine shop and heat treating department has changed this, but nevertheless, these experiences make one look warily on suggestions for high duty steels.

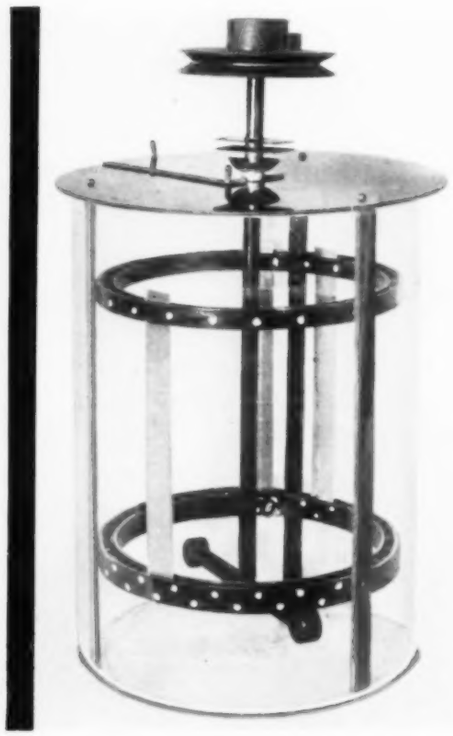
F. Grimshaw Martin.

Standards for Corrosion Tests on Aluminum

Berlin, Germany — Tentative standards for determining the corrosion resistance of aluminum and its alloys have recently been prepared by the National Bureau for Metal Pro-

tection. These specifications apply primarily to sheet material but can also be used, with slight alterations, in testing welded, riveted, or screwed joints, protective coatings, and cast aluminum. The laboratory tests approximate service conditions as nearly as possible but it is recommended that they should be accompanied by service tests wherever possible.

Test specimens are to be taken adjacent to each other and in rotation so that at least three groups of specimens are taken from different places, each of which is subjected to corrosion for three or more periods of time. Sheet specimens are taken parallel to the direction of rolling. Chemical analysis, mechanical properties, and previous treatment of the material should be noted. Specimens are generally 2x$^3/_4$ in., but if tensile tests are to be made, 8x$^3/_4$ in. is preferable. For weathering tests specimens 4$^3/_4$x8 in. are best. Thickness is measured before the test at both ends and in the center of each bar.



Standard Device for Corrosion Tests in Moving Solutions. A 9-in. battery glass encloses a bakelite stirrer and no more than 20 specimens 3$^1/_2$ in. from the axis. Cage is also of bakelite, or nonmetallic material inert to specimens under test

Specimens are cleaned in pure, light benzine, benzol, or a mixture of both. More volatile substances, such as ether and acetone, are undesirable because of the cooling effect of evaporation. Drill-holes will increase corrosion attack, but if drilling is unavoidable, the holes should be not more than $^1/_8$ in. diameter and in the top center of the bar. Suspension hooks should be of material which will have no influence, and edges should not be covered.

There are three main types of tests: *(a)* Laboratory, *(b)* weather exposure, and *(c)* seawater exposure tests. In making laboratory tests at least 6 c.c. of corroding solution is used per square centimeter of submerged area. Concentration of solution is maintained by adding distilled water to compensate for evaporation. Solutions must be renewed as corrosion proceeds and in making check tests this must be done in all vessels at the same time. Recommended solutions are of the following concentrations: 0.1, 0.2, 0.5, 1.0, 2.0, and 5.0 normal. Tests are usually made at room temperature, but if more complete data are required, the temperature should be raised by 10° increments in a thermostat.

Tests should be performed in diffused daylight and, if quiescent solutions or standing tests, in open vessels. Air currents must be avoided, and the vessel should be covered if the solution evaporates rapidly. Specimens of different composition or treatment should not be tested in the same vessel.

In addition to quiescent laboratory tests, stirring and accellerated stirring tests are made. When test pieces are small, the solution may be agitated by an air current, but in most instances a stirring apparatus such as the one illustrated is to be used. The velocity of the solution is then measured in revolutions of the stirrer per minute; 135 is recommended. In reporting results the diameter of the vessel, quantity of solution, type and size of stirrer, and distance of specimens from center of stirrer should be carefully reported. *(Continued on page 120)*

Dinanderie

early copper and brass work

A Depository for a Sacred Relic, Made of Gilded Copper in the Form of a Small Romanesque Church. Cleveland Museum of Art

IN BELGIUM, on the Meuse River, is a quiet summer resort known as Dinant. Its inhabitants now number less than 7,000 and yet it was once such a famous manufacturing center that its name has been perpetuated to designate the products of one of the important crafts of the middle ages. These products are works in copper, brass, and bronze, most of them artistic and ornamental and designed for ecclesiastical purposes, the remainder for domestic and commercial use. They are known collectively as "dinanderie," for although excellent examples of the craft were produced all over Europe, Dinant, with its fifteenth century population of 60,000 (about 8,000 of whom were workers in copper) was the industry's center.

The raw materials for the making of bronze were not so readily available at Dinant as might be expected. Copper had to be imported from the Hartz Mountains in Germany or from Scandinavia; tin from England. However, large deposits of calamine ($ZnCO_3$) in the banks of the Meuse River were an important factor. Although a little zinc had been used in bronze before this time, brass was not manufactured in any great quantity until its development at Dinant. Another advantage was the "derle" or plastic clay used for molds and crucibles which was found in large quantities on the opposite bank of the river. But the success of this city may be credited not so much to its natural resources as to its strategic commercial location and to fortunate alliances with important trade leagues of the Middle Ages.

It was only from the eleventh to the end of the fifteenth century that the craft flourished in Dinant. However, works produced both earlier and later than this are similar enough to be classed under the general term "dinanderie"; also are included products from such distant countries as France, Germany, England, Italy, and Spain.

Ewers, or Aquamanile, Used in the Middle Ages for Water for Washing Hands at Meals. Ordinarily cast of bronze in grotesque shapes. From the collection of 14th century German art at Metropolitan Museum of Art

Perhaps the best records we have of the processes and methods used are contained in the memoirs of a German monk, Theophilus, who, in the eleventh century, wrote a detailed and very informative *Treatise Upon Divers Arts.* One of his manuscripts contains directions for founding an elaborate censer by means of the "lost wax" process. This censer is highly decorated with four tiny towers, figures of the 12 apostles, of the prophets, and of the virtues, all bearing a wealth of minute decoration.

The censer is cast in only two molds. Clay for the cores is to be beaten, dried, ground, sifted, mixed with water, well beaten again, and formed into what Theophilus calls "nuclei," the inside core, of correct form and shape. Pure wax is then warmed, and rolled and pounded into thin sheets. These sheets are cut into appropriate sizes and molded over the core with an iron tool, great care being taken that the wax shall be everywhere of the same thickness. Next the decorative pattern has to be carefully traced in the warm wax with pointed tools. "Then," says Theophilus, "the tunnels and air holes being placed in every part, you plaster thin clay carefully about it, and will dry it in the sun, and you do this again, and a third time; these parts are now called molds." When the molds are thoroughly dried, the assembled combination of mold, wax and core is warmed, whereupon the wax melts and may be poured out of the cavity.

Again to follow Theophilus' account, while the brass is being melted in one furnace, the molds are heated in another. The heating furnace is made of stones and is large enough so the molds can be surrounded with coals. As soon as they are heated to glowing, they are removed to the casting pit, below the surface of the ground, and surrounded with earth. The molten brass is allowed to run from the furnace through clay troughs and down into the molds. (In casting large pieces, several furnaces with converging troughs were placed in a semicircle around the casting pit. The mold could thus be filled more quickly.)

The molds must be cooled where no moisture can reach them; otherwise the nuclei will swell and burst. A certain amount of filing, "sculping," and scraping is necessary after the clay has been removed, and the brass must be cleaned with sand and a piece of wood, slightly crushed at the end, before gilding.

Brass which is to be gilded must be free from lead, and this Theophilus calls "aurichalcum" as distinguished from "aes" or brass to

be used without decoration. For aurichalcum "burnt" copper must be used. The brass is melted in a clay crucible and strongly blown with bellows. When the proper temperature is reached, it is covered with fine coal ashes and stirred with a wooden stick. The oxidized lead will adhere to the ashes. The blowing is repeated and ashes are added until a piece of the glowing brass held in pincers and struck with a hammer will not break.

Mediaeval Molding Practice

Casting of bronze by the Dinant artisans was done very much as Theophilus describes it. The clay used for cores probably contained a mixture of broken bricks and pounded crucibles, well beaten and smoothed. The molds were made of dried clay, pounded crucibles, and plaster of paris, rubbed with water to the consistency of cream. Only a very thin first layer of molding material could be spread over the wax, in order that the delicate tracings might not be destroyed, and this was then covered with several heavier coatings. Small rods of bronze or iron (chaplets) were inserted between the mold and core to hold them in place after the wax was removed. Numerous ducts and air vents had to be provided, as well as openings to scrape out the clay of the core.

The preparation of bronze for casting was relatively simple, since tin was usually obtained in the pure state and could be mixed with pure copper in the correct proportion. Brass, however, was made with the calamine of the Meuse River banks, which contained an indefinite proportion of zinc. The calamine had to be ground into a powder and mixed with the copper and the two fused. If the brass was not right, more calamine could be added.

Not all dinanderie, however, was made in the foundry. Indeed, the manufacturers were generally known as "batteurs de cuivre" or copper beaters. Beaten work was made of pure copper and was used mainly for small pieces, such as reliquaries (ecclesiastical articles for entombing holy relics), book covers, and hollow vessels to be gilded. Larger pieces, such as fonts, lecterns, and candlesticks, and pieces to be decorated with niello, champlevé or cloisonné enamel, were usually cast.

Copper for hammering and working was prepared in thin plates. Repoussé designs were made by either outlining the pattern on the surface and beating it into the back of the plate, or by placing the plate face down in a wooden mold and hammering it into shape. The surface could then be finished off by filling the inside hollows with lead or resin to resist the pressure of the tools and chasing the fine lines and markings with sculping tools and chisels.

Much of the dinanderie was decorated with champlevé or cloisonné enamels, some was set with jewels, but by far the most important ornamentation was gilding. This delicate process is also carefully described by Theophilus.

Small pots are filled with thin strips of gold alternating with layers of tile or dried red clay and salt and heated. Eight times as much mercury by weight as gold is measured out and ground up with the gold mixture in a hot crucible. A glowing, curved iron tool is used for this purpose. When the mass is completely liquefied, it is poured into water, washed carefully, and dried on a linen cloth. The article to be gilded is rubbed with a linen cloth dipped in a hot solution of ground winestone, salt, and mercury, and then rubbed with hog's bristles. The gold is applied with a gilder, which is a copper chisel into the edge of which a small amount of mercury has been rubbed. After the gilt is applied, the object is again smoothed with hog's bristles and polished with copper wire.

It is to be regretted that so much of the dinanderie has been destroyed or remelted during the intervening centuries — yet enough pieces remain to testify to an artistic skill and

Plaque Representing the Crucifixion Made in the 12th Century of Bronze Gilt. Courtesy Metropolitan Museum of Art

ingenuity which could hardly be duplicated today even with our increased knowledge and improved methods and equipment. To produce these beautifully elaborate articles with such unscientific and inadequate methods as those described above, the ancient metalworker must have been endowed with a large share of patience, persistence, and fortitude. The hazards and uncertainties of making a large bronze casting, even as late as 1558, are vividly related by the Renaissance artist, Benvenuto Cellini, in the description of the casting of the "Perseus" contained in his *Autobiography*.

Cellini's difficulties were caused not so much by elaboration of detail as by the size of his statue, which measured nearly 8 ft. in height. He also used the lost wax process essentially as described by Theophilus. The clay core of the statue was supported with an iron framework, and the outer mold was also strengthened with iron girders. After the wax was melted out through numerous vent-holes (Cellini stresses the desirability of having a large number of these), the mold had to be moved from the baking oven into the casting pit by means of a painstakingly constructed windlass. The mold was liberally banked with earth and supplied with earthenware tubes for air ducts. The melting furnace had previously been filled with pigs of copper and bronze so arranged that flames from a pinewood fire could play freely through them.

All went well until the intense heat of the furnace set fire to the roof of the workshop. This was put out without much damage, but rain falling through the hole in the roof cooled the furnace to below the melting point of the metal. However, the roof was patched, more wood heaped on the fire, and the draught increased. Cellini then relates how, sick and exhausted, and sure now that all would be well, he went to bed, after leaving careful instructions with his helpers.

But what was his dismay to be wakened several hours later and told that the metal had caked and the statue was ruined! He ran out and piled dry oakwood (which makes a hotter flame than pine) on the fire and threw half a pig (60 lb.) of pewter into the furnace. Stirring the bath vigorously, he soon saw it liquefy again. Just at this point, the cap blew off the

Cellini Describes Vividly in His Autobiography the Exciting Events During the Casting of His Famous "Perseus"

furnace and the bronze started to bubble out over the top, making it necessary to open the plugs and allow the metal to flow into the channels and into the mold. But alas! the metal was still too viscous and flowed all too slowly. Determined not to have his statue ruined, the resourceful artist sent for his pewter dishes and platters (200 pieces in all) and threw them also into the furnace and into the channels. It worked. The pewter melted; the metal bubbled and flowed faster and more freely into the mold; and the Perseus was saved!

Two days later the statue had cooled sufficiently to allow removal of the mold. It was dug out of the banked earth with fear and trembling, for not a bit of metal had remained in the furnace — not a bit was to be found in the channels. Great was the astonishment, therefore, to find that the statue was entirely complete. Exactly the right amount of metal had been poured into the mold! To Cellini it could be nothing less than a miracle, and with customary fervor, he writes, "In my great astonishment, I seemed to see in this the hand of God arranging and controlling all."

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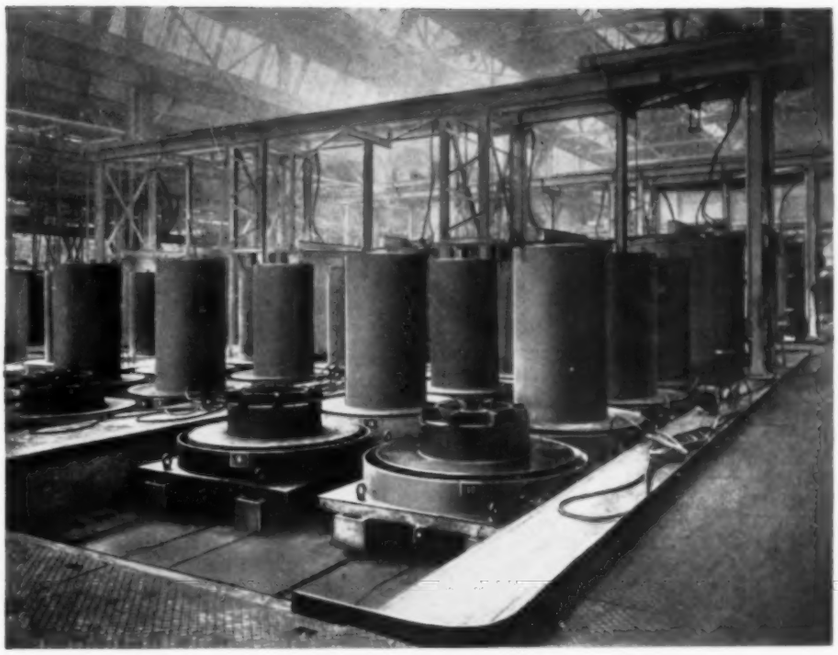
General view of annealing plant for cold strip. A tower with traveling hoist spans each group of 6 furnaces. Foreground shows bases and hoods in the cooling position



WHY

24 electric bell-type furnaces were installed in this cold-strip mill:

1. Improved finish
2. Uniform hardness
3. Shorter annealing cycle
4. Reduced costs
5. Better working conditions

Loading end of a group of 6 furnaces, showing loaded bases ready to be placed in heating chambers under tower

A PROMINENT steel company recently modernized its process for bright-annealing steel strip by installing 24 electric bell-type furnaces — 12 of which were built by General Electric.

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solder between them, wrap the pile carefully in asbestos, clamp the assembly tightly, heat it to the melting point of the solder, then squeeze the hot combination in a press. A certain percentage of the finished bi-metal sheet would be rejected after rolling because of incomplete soldering, or entrapment of droplets of flux.

A furnace for this same operation has a power driven screw press built into a space between heating chamber and cooling prolong. Bars of bi-metal, with a solder sheet (but no flux) between them, are heated in a hydrogen atmosphere to the flushing temperature of the solder. The function of the hydrogen atmosphere is, of course, the same as the flux — to remove any oxide from the abutting surfaces. When the correct temperature is reached, the hot pile is pushed ahead, out of the hot region, into the space between upper and lower platens of the press, and pressure of correct and measured amount immediately applied and held until the billet has cooled below the setting point of the solder. Pressure is then released and the billet moved on into the water cooled extension of the furnace.

Costs of bright annealing and the associated operations have been continually lowered because the successive furnace designs have been improved, the method of generating gases has been perfected, and means adopted for its conservation, and the developmental costs have been absorbed and written off. Consequently many operations on cheap metals are now within the range of practicability, whereas once only the unusual applications could be considered possible or economical.

Atmospheres have been cheapened by making tighter furnaces, and closer fitting doors. Furthermore, the development of ammonia dissociators has provided a cheaper source of the necessary hydrogen. "Electrolene," a General Electric development, is also available for large furnaces or an installation of smaller ones.

Dissociated ammonia is usually introduced into the heated chamber near the hottest region. If the furnace is a continuous one, the pressure is slightly above atmospheric, so the outflowing gas effectually keeps the air out of the heated chamber and a lazy flame burns at the opening. In some furnaces a stream of nitrogen is also introduced into the cooling chamber, at sufficient pressure to sweep out any air which might enter through the discharge door. This nitrogen is made by burning the dissociated ammonia in a measured amount of air, and condensing the resulting water vapor.

In most furnace operations it is all right to allow a nitrogen atmosphere to build itself up in the cooling chamber by natural means. The hot dissociated ammonia diffusing from the heating zone will burn in any air which filters in through the door opening (according to the above reaction), and the water vapor condenses against the water-cooled iron sides of the chamber, and drains off through a suitable trap in the floor. This water vapor has little or no effect on the surface of most metals encountered, although it must be swept quickly out of furnaces heating steel. Hence steel annealers operate under a somewhat higher head of gas.

Temperatures of the operation are moderate, so the heating elements present no problem. Brasses and silver are properly annealed at heats ranging from 900 to 1,150°. Silver soldering is usually done between 1,500 and 1,600° although some compositions can be handled as low as 1,400, and still others require as much as 1,750° F. Nichrome heating elements in a hydrogen atmosphere have an almost indefinite life at these temperatures — furthermore, heat resisting alloys are available for conveyors and other furnace parts. Copper brazing requires 2,100° F., which is a little more severe, but easily met by properly selected alloys.

From this brief account it may be seen that a wide variety of successful applications of bright annealing have been and are being made. It is a process which deserves and will get increased attention from fabricators of metal in all lines. It is performed at moderate temperatures, in properly designed furnaces, and with readily controlled inexpensive atmospheres. It has been developed because the process, when introduced in a manufacturing line, has lowered the cost of the finished article and improved its uniformity and quality.

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As shown on page 63, the tip is separately mounted on a hollow handle through which the connecting leads are carried to the indicating pyrometer. The latter has a 5-in. dial, and is capable of measuring temperatures up to 2,400°. The dial is divided into 120 scale divisions of 20° each. Quick, close reading is therefore very readily done.

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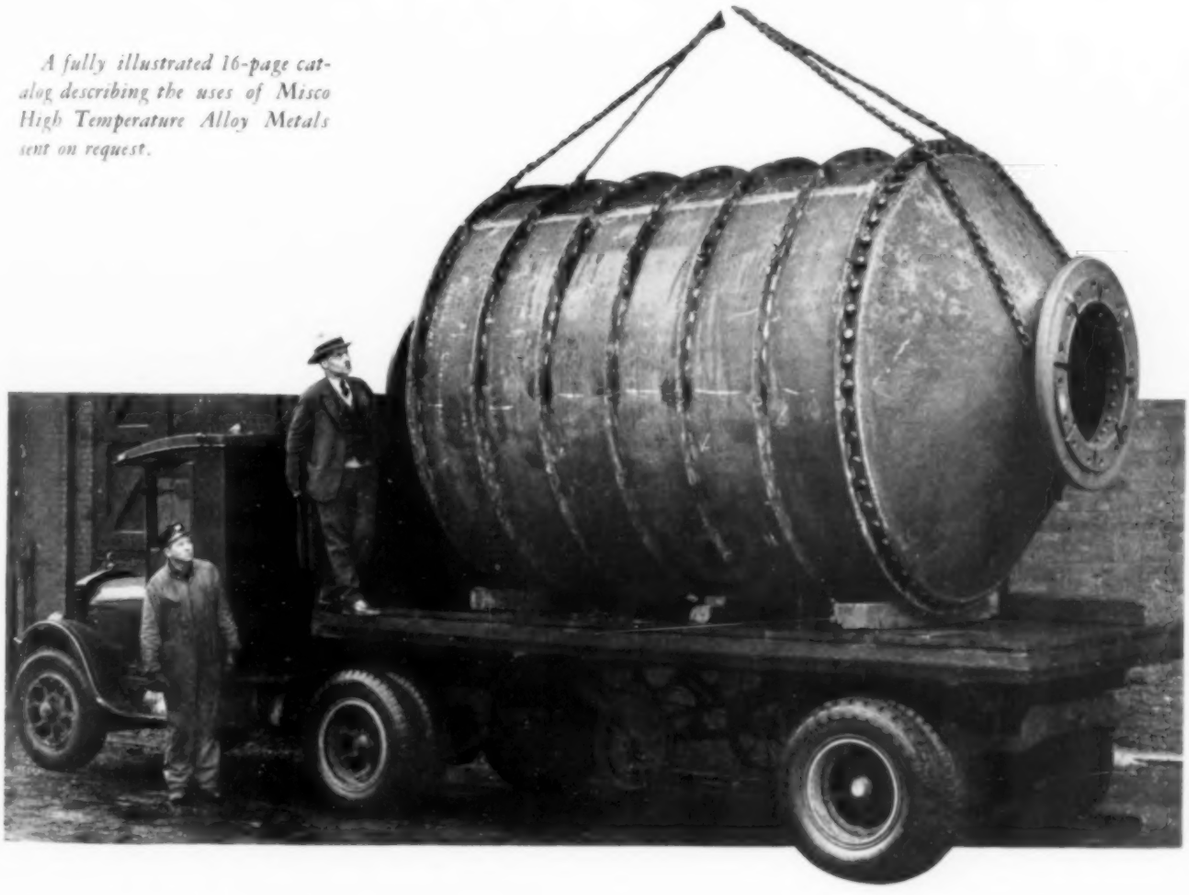

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TO KEEP YOU ABREAST OF THE TIME

Cold Finished Bar Bulletin—Joseph T. Ryerson & Sons, Inc. Bulletin describing the wide variety of shafting, screw stock, and open-hearth case carburizing steels in use today. A range of products is given, a list of standard tolerances and S. A. E. specifications. Bulletin O-50.

Automatic Control Type Pyrometer—The Brown Instrument Co. Pamphlet describing this new instrument with control through mercury switches. Patented feature shuts down furnace in case of thermocouple failure or opening of circuit or short circuiting. No relays. Bulletin O-3.

Safety Equipment for Pickling—Weaver Brothers Co. Literature describing and illustrating equipment for safely carrying out pickling operations on a wide variety of products. Bulletin O-52.

Automatic Temperature Control—Leeds & Northrup Co. Deal with the subject of automatic temperature control which suggests both the limitations and tremendous advantages within its field. For your copy of "Potentiometers for Automatic Temperature Control" ask for Bulletin O-46.

"Economics of Industrial Heating"—W. S. Rockwell Co. Leaflet discussing advantages and disadvantages connected with the use of various fuels and electricity when used for industrial heating operations. Bulletin O-49.

Enduro Free-Cutting Stainless Steel—Republic Steel Corp. Folder of physical properties and other data on a new corrosion and heat resisting stainless steel said to have the free cutting qualities of Bessemer screw stock. Bulletin O-8.

Industrial Gas Heat—American Gas Association. A veritable textbook on the uses of gas heat in industry, profusely illustrated with photographs of installations, etc. Bulletin A-10.

Tool Steels—Bethlehem Steel Co. Newly revised catalog describes the various grades of Bethlehem tool steel, explains the application of each grade and gives explicit directions for heat treatment. Bulletin A-76.

Rotary Retort Furnace—Hevi Duty Electric Co. Bulletin on Electric Rotary Retort Furnace used for carburizing steels with gas as a carburizing medium. Illustrations and specifications are also given. Bulletin A-44.

Aluminum Welding—Aluminum Company of America. Instruction card to be hung in the shop for ready reference, giving directions for welding aluminum. Bulletin A-54.

Production Carburizing—American Gas Furnace Co. Bulletin describing the purpose, principles involved, types of machines used and how they are constructed for production carburizing, also nitriding, bright annealing, hardening, annealing and tempering. Bulletin A-11.

Thermocouple Protection Tubes—Michigan Steel Casting Co. Bulletin on Misco Rolled Thermocouple Protection Tubes for use in furnaces and in liquid heating mediums at temperatures up to 2200 degrees Fahr. Bulletin A-12.

The Modern Soaking Pit—Surface Combustion Corp. Attractive booklet of layouts and photographs giving the advantages of the one-way fixed soaking pit. Bulletin A-51.

Industrial Application of the X-Ray—General Electric X-Ray Corp. Booklet gives many examples of the use of the X-Ray in the industrial field. Profusely illustrated with radiographs of castings, welds, assemblies, etc. Bulletin M-6.

Hacksaw-Ology—Simonds Saw and Steel Co. Book illustrating and describing the uses of hack saws. Bulletin JJ-69.

Steel Users Reference Book—William Jessop & Sons, Inc., issue a booklet showing compositions, thermal treatment, mechanical properties and uses of various types of tool and constructional steels. The theories of hardening are discussed in their practical aspects. Bulletin M-61.

Stainless Steels—United States Steel Corp. Booklet describing various stainless and heat resisting alloy steels produced by subsidiary companies. Tables of chemical compositions and physical properties are included, also recommended procedures for use, polishing methods, etc. Bulletin JJ-79.

Case Hardening—Roessler & Hasslacher Chemical Co. 60-page booklet on case hardening and heat treatment of steel with cyanides; also discussion of coloring of steel with R & H heat treating salts. Methods of analyses, tables, etc., are included. Bulletin JJ-29.

Electric Pot Furnace—American Electric Furnace Co. The new "American" electric pot furnace for lead, salt or cyanide is completely described in a bulletin recently issued by the above company. Bulletin JJ-2.

Fatigue Testing Machine—Thompson Grinder Co. Interesting data on fatigue testing and description of the rotating beam type of fatigue testing machine are given in Bulletin M-23.

High Test Welding Rod—The Linde Air Products Co. A 12-page booklet describing the qualities and advantages of high test welding rod. Extensively used for fabrication of pipe lines, pressure vessels or other welding operations where high strength and economy are required. Bulletin JJ-63.

Ferro Alloys and Metals (Third Edition)—Electro Metallurgical Sales Corp. Describes current practices with specific reference to the "Electromet" products

Trade Pamphlets Continued

supplied to the metallurgical industry by this organization, together with suggestions for their use in both the ferrous and non-ferrous industries. Bulletin JJ-16.

Ingot Molds—Gathmann Engineering Co. The subject of ingot molding is covered in a new book on this subject. Numerous illustrations of the effect of various methods of finishing and casting on the reliability of steel products are given. Bulletin S-13.

Non-Metallic Heating Elements—Globar Corp. Bulletin of technical information concerning Globar non-metallic electric heating elements which are used for a wide variety of industrial heating applications. Bulletin J-25.

Heat Treat Supplies—Case Hardening Service Co. Supplies and equipment for the modern heat treating plant are described in a 24-page catalog. Numerous illustrations and many helpful suggestions for economical heat treating and equipment operation are given. Bulletin H-15.

Grinding and Polishing Machine—E. Leitz, Inc. New pamphlet describing this double spindle machine provided with an automatic arrangement so that the operator need not give personal attention to polishing of specimens. This instrument is offered at a price attractive to small laboratories. Bulletin A-47.

Inclined Binocular Body—Bausch and Lomb Optical Co. Leaflet describing the inclined binocular body for microscopes. This device allows the microscopist to sit at the microscope in an unstrained position, and to use both eyes, thus reducing eye strain. Bulletin A-35.

Carbofrax Veneered Arches—The Carborundum Co. Pamphlet dealing with Carbofrax veneer blocks as applied to various types of arches which are subjected to high temperatures as heat treating furnaces, forge furnaces, electric furnaces, tunnel kilns, etc. Bulletin A-57.

Practical Metallurgy for Engineers—E. F. Houghton and Co., Philadelphia. A 435-page book by the Houghton Research Staff, covering practical metallurgy in all its phases. Copies of the third edition are obtainable by sending $3.00 directly to the above company.

Conveyor Belts—Wickwire Spencer Steel Co. Portfolio describing the new heavy duty Atlas link belt and the new Delta link plate belt, designed to carry very small as well as large materials through high temperature operations. Bulletin A-37.

Gasalyser—Chas. Engelhard, Inc. New bulletin which describes the Gasalyser, a new portable instrument for gas analysis, in addition to gas analysis temperature measurements can be made with the same instrument. Bulletin A-14.

Bright Annealing—Process Engineering and Equipment Corp. Descriptive material on Preeco furnaces for bright annealing of steel, brass, nickel silver, copper, nickel and alloys. Bulletin A-81.

Electric Furnaces—Hoskins Mfg. Co. Complete description of Hoskins electric furnaces of the tool-room type and those for light production. Bulletin A-24.

Anti-Friction Bearings—Timken Roller Bearing Co. Reprint of an article on load and power tests on anti-friction bearings for steel mill service. Bulletin A-71.

Railroad Applications of Nickel Alloy Steel—International Nickel Co. A series of 8 recommended specifications covering forging billets, normalized and tempered low-carbon forgings, boiler and firebox plates castings, bolt steel, main frames, staybolt steel, cylinder iron. Bulletin S-45.

Thermit Welding—Metal & Thermit Corp. A book describing their Thermit welding process in detail. Bulletin S-64.

Furnaces for the Steel Industry—The Electric Furnace Co., have issued a four-page folder illustrating and listing several electric and fuel fired furnaces of various types they have installed in steel plants. Bulletin S-30.

The Coreless Induction Furnace in the Steel Industry—Ajax Electrothermic Corp. Reprint of a paper describing recent developments in high frequency coreless induction furnaces and their probable applications. Bulletin S-41.

Electric Steam Generators—General Electric Co. Booklet describing and illustrating G. E. electric steam generators for process work. A list of applications is included showing how these generators may be used in a wide variety of industries. Bulletin S-60.

Carburizing Retorts—Driver-Harris Company has issued a bulletin featuring carburizing retorts. This bulletin gives data and advantages of "Nichrome" heat resisting alloy in the form of carburizing retorts. Bulletin S-19.

Electric Heat Treating Furnaces—Ajax Electric Co., Inc. Photographic description of new electric furnaces for annealing wrought products, such as sheet, wire, tubing, rod, etc. Bulletin S-83.

Recorder Controller—Bristol Co. Catalog describing and illustrating Bristol's air-operated free vane recorder controller. Bulletin O-56.

Aluminum Alloy Castings—British Aluminum Co., Ltd. Booklet contains information on aluminum alloys used in all manner of light alloy castings. Contains a quantity of technical information for foundries and users of aluminum alloys and alloy castings. Bulletin O-78.

Scale Prevention—Dearborn Chemical Co. Booklet describing latest scientific methods of treating water for prevention of scale, corrosion and foaming in steam boilers, dealing with related problems in connection with scale and corrosion in other power plant equipment. Bulletin O-36.

Heat and Corrosion Resistant Alloys—General Alloys Co. A new bulletin is available on chrome-nickel and straight chrome heat and corrosion resisting alloys. Bulletin O-17.

Hy-Ten Alloy Steels—Wheelock, Lovejoy & Co., Inc. "Pertinent Points" folders covering physical properties, heat treatment and applications of all grades of Hy-Ten Special Steels. Bulletin O-22.

Refractories—E. J. Lavino & Co. Literature on Kromepatch and Plastic K-N chrome ore refractories for industrial furnaces. Bulletin O-40.

Metal Progress, 7016 Euclid Ave., Cleveland.

Please have sent to me the following literature as described under "Trade Pamphlets" in the October METAL PROGRESS. (Order by number.)

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Correspondence & Foreign Letters

Accellerated stirring tests are of practical value when the corrodibility of the material in the shortest possible time is desired. Strong solutions are necessary but they should not be beyond the limits of practical conditions. An agent recommended for performing accellerated sea-water corrosion tests on aluminum and its alloys is a 0.5 N (about 3%) sodium chloride solution which contains 0.1% hydrogen peroxide.

Another type of laboratory test is known as the "wet and dry" test, in which the specimens are alternately dipped in the solution and allowed to dry in air. Periods of immersion and emersion are determined by the length of time for the specimen to become completely wet and completely dry, and should be reported in the results.

Spraying tests are to be made on a specimen suspended in a closed vessel wherein the corroding solution is blown by means of compressed air so as to produce a fine fog. Spraying should be sufficient to form a thin layer of small, individual droplets on the surface; too much solution will form large drops which will drain off the specimen. Compressed air must be washed and free from oil and acid. Spraying should be succeeded by a period of drying.

In weather and sea-water exposure tests, specimens are to be attached to wooden frames in such a way that no strains are produced. In weathering tests the frame should be at least 20 in. above the ground and inclined at an angle of 45° toward the south. Accumulation of moisture should be avoided.

In evaluating test results five points must be taken into consideration:

1. *Change in surface.* Amount of corrosion is measured by the ratio of corroded to uncorroded portions, which is computed by means of macrographs and micrographs taken both before and after testing. Location and nature of attacked spots should also be described.

2. *Change in microstructure.* Extent of micrographic investigation is optional with the investigator but the cross-sections examined should be marked on a photograph of the surface. In pitted specimens, the nature and depth of the spots should be noted.

3. *Change in weight.* The exposed specimen should be free from corrosion products before it is weighed. An efficient cleaning agent is cold dilute nitric acid (about 5%). Weight changes are accurately and simply reported in grams per unit of surface area.

4. *Change in tensile properties.* Tensile strength, elongation, drawing quality, and bending quality are determined by the usual test methods before and after attack.

5. *Nature of corrosion products.* These sometimes take the form of protective coatings. The report should cover color, condition, and form of the film, and sometimes should include chemical analyses.

In plotting test data, individual results, average values, and values computed per unit of area are all to be tabulated.

GEORG GOLDBACH

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